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SYSTEM CERTIFICATION PROCEDURES AND
CRITERIA MANUAL FOR DEEP SUBMERGENCE
SYSTEMS

Naval Material Command
Washington, D. C.

July 1973

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**SYSTEM CERTIFICATION PROCEDURES
AND CRITERIA MANUAL
FOR
DEEP SUBMERGENCE SYSTEMS**



NAVAL MATERIAL COMMAND

NAVAL SHIP SYSTEMS COMMAND

NAVAL FACILITIES ENGINEERING COMMAND

DEPARTMENT OF THE NAVY
WASHINGTON, D. C. 20362

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J. E. Lundberg
17 Dec 74

RECORD OF CHANGES

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FOREWORD

Through the Chain of Command, the Naval Ship Systems Command (NAVSHIPS) and the Naval Facilities Engineering Command (NAVFAC) have been assigned responsibilities for the development, promulgation, and implementation of procedures and criteria by which personnel safety of manned non-combatant Deep Submergence System (DSS) is to be evaluated. NAVSHIPS has certification responsibilities for shipboard systems and NAVFAC for shore based systems. These procedures and criteria were known as the Material Certification process.

Experience has shown that the word "Material" when used in conjunction with certification tended to place undue emphasis on traceability and chemical analysis of individual system components to the exclusion of other equally important certification supportive procedures. While traceability and chemical analysis are important, other methods of safety assurance must also be used to satisfy the Certification process. For example, design interrelationships of components as a system, fabrication techniques and proof testing must also be evaluated by the Certification Authority. Therefore, to avoid confusion, the term "Material Certification" has been replaced by the term "System Certification."

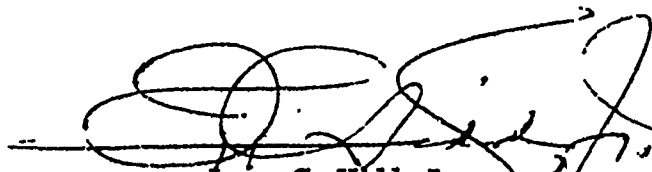
The knowledge contained herein is the result of a combined effort by the Naval Ship Systems Command and the Naval Facilities Engineering Command and presents a viable set of guidelines through which the designer and/or builder of submersibles, in or on bottom habitats, diving systems, hyperbaric facilities, and attendant handling systems can gain maximum reasonable assurance that the lives and well being of Naval personnel using these deep submergence systems will be safely preserved. These System Certification guidelines are not intended to provide rigid procedures for construction or to stifle initiative and innovation in the use of new methods, components, systems or materials.

This manual supersedes the following individual publications:

- A. "Hyperbaric Facilities, General Requirements for Material Certification," Naval Ship Systems Command - Naval Facilities Engineering Command, Department of the Navy, Washington, D. C. NAVSHIPS 0994-007-7010, NAVFAC P-422, May 1970.
- B. "Material Certification Procedures and Criteria Manual for Manned Non-Combatant Submersibles," Naval Ship Systems Command, Department of the Navy, Washington, D. C. NAVSHIPS 0900-028-2010, September 1968.
- C. "Diver Equipment, General Requirements for Material Certification," Naval Ship Systems Command, Department of the Navy, Washington, D. C. NAVSHIPS 0994-012-3010, June 1971.

Custodianship and responsibility for maintaining the technical content of this manual to meet the Navy's needs rests with the Naval Ship Systems Command who will consult with the Naval Facilities Engineering Command concerning their areas of responsibility prior to issuing changes. Changes and/or recommendations to improve the content of this booklet should be directed to NAVSHIPS OOC, Washington, D. C. 20362.

Certification of this publication as an official command publication has been reviewed and approved in accordance with the Secretary of the Navy Instruction 5600.16.

A large, stylized handwritten signature in black ink, appearing to read 'Isaac C. Kidd, Jr.', is written over a horizontal line.

Isaac C. Kidd, Jr.
Admiral, USN
Chief of Naval Material

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CHAPTER I

GENERAL INFORMATION

1.1 INTRODUCTION

This Manual is presented as a set of guidelines for the designer and/or builder of a Manned Deep Submergence System (DSS), including any non-combatant submersible, in or on bottom habitat, diving system, diver equipment or hyperbaric facility, that is intended for Naval use. IT IS NOT INTENDED EITHER TO PROVIDE RIGID PROCEDURES FOR CONSTRUCTION OR TO DISCOURAGE INITIATIVE AND INNOVATION IN THE USE OF NEW METHODS, COMPONENTS, SYSTEMS, AND MATERIALS; NEITHER IS IT INTENDED THAT THIS MANUAL SHOULD BE INVOKED AS A CONTRACTUAL DOCUMENT. The translation of System Certification criteria and procedures into technical contractual specifications is the responsibility of the DSS development program manager or "sponsor."

The objective of the Certification process is to verify that a Deep Submergence System provides acceptable levels of personnel safety throughout the specified operating range of the DSS when used in accordance with approved operating and maintenance procedures. The certification process is concerned with establishing maximum reasonable assurance of the recovery of DSS personnel without injury, and the deliberate avoidance of conditions that imperil the lives and well-being of operating personnel. The certification of a DSS does not relieve its sponsor from his responsibility to maintain a safe DSS on a continuing basis.

DSS personnel are considered to be the occupants, passengers, divers, pilots, etc. The safety of handling system personnel and external DSS equipment operators is not normally covered by the System Certification process except when the lives and well-being of DSS personnel would be imperiled. The application of Deep Submergence System Certification Criteria and Procedures to routine shore and marine industrial safety (otherwise covered by MIL-STD-882, etc.) is not intended.

The principal participants in the System Certification process are: (1) the Deep Submergence System Sponsor who is applying for or sustaining System Certification; and (2) the System Certification Authority (SCA), NAVSHIPS or NAVFAC, who implements the System Certification Process. The Naval Material Command (NAVMAT) maintains cognizance and effects priorities.

The responsibility of the Certification Authority to verify system adequacy, within the specified operational limits with respect to personnel safety, extends to the evaluation of the established DSS operation and maintenance procedures.

Mission reliability is of concern to the Certification Authority only as it relates to the ability of the DSS to effect recovery of DSS personnel without injury.

Effective DSS Certification with a minimum of difficulties is dependent on:

- a. Primary Duty Assignment of a knowledgeable individual to represent the sponsor in the negotiations relative to the certification of the candidate DSS.

b. A clear understanding of the certification process by the sponsor's representative.

c. A clear understanding of the DSS by the Certification Authority.

d. Frequent negotiation between the sponsor and the Certification Authority.

The importance of frequent negotiation (free exchange of information) between the Sponsor and the Certification Authority cannot be over-emphasized. Only through negotiations can the Sponsor and the SCA establish a realistic balance between conflicting cost/time reduction objectives and the certification objectives and also only in this way can the Certification Authority gain sufficient knowledge and understanding of the candidate DSS to permit effective and practical accomplishment of the certification objectives.

A major function of a DSS is to provide an acceptable life supporting environment of the correct temperature, composition, and pressure. Exceeding the permitted ranges of the various environmental factors could have severe or fatal consequences. In the case of diver involvement the time required for decompression cannot be reduced significantly, even in an emergency. Design criteria are therefore considered which directly concern the safety of personnel.

Specific information on materials and procedures is contained within the appendices to this manual. Sources of information that the System Certification applicant may find beneficial are listed in the bibliography included in the appendices.

Before proceeding with the contents of this manual, a review of the following "Glossary of Terms" is advisable.

1.2 GLOSSARY OF TERMS

For purposes of this Manual, the following words or phases are as defined:

Accessibility to Vital Equipment	The ability to reach, read and/or operate vital equipment and devices.
Accident	A happening that is not expected, foreseen, or intended under normal circumstances.
Alteration	A change from the as certified design, material, configuration, or performance.
Applicant/Sponsor	The Agency/Organization that is making application for System Certification or Recertification of a DSS. For DSS being developed, the Applicant/Sponsor will normally be that Agency/Organization tasked with development of the capability being supplied by the DSS. For existing DSS, the Applicant/Sponsor will normally be that element within the organizational chain responsible for operational readiness and deployment of the specific DSS.
Appurtenances	An accessory added to a major component (e.g. viewports, hatches, jettisoning equipment, support rails, connectors, piping, et al.).
Breathing Gas Supply Equipment	Equipment that is used to compress, condition, mix, store, distribute, or otherwise handle breathing gas.
Builder	Contractor or agency who constructs the DSS.
Casualty	An accident usually resulting in physical injury to personnel, and/or damage or interruption of the normal operation of the DSS.
Catastrophe	Any great or sudden disastrous malfunction which jeopardizes the safety of the DSS personnel.
Certificate	The document attesting to the System Certification granted by the SCA.
Certifiable	See System Certification.

Certification	See System Certification.
Certification Scope	A list defining those systems, sub-systems, components, portions of the DSS, maintenance and operational procedures which are needed to preserve the physical well-being of the DSS personnel. (See Chap. II)
Deep Submergence System(s) (DSS)	Any manned, non-combatant submersible, in or on-bottom habitat, hyperbaric facility, deep diving system or diving equipment, including attendant systems, providing or supporting the ability of naval personnel to operate under water. (See paragraph 1.4)
Diver	An individual who is qualified in accordance with current Bureau of Naval Personnel instructions.
Emergency	A sudden unexpected malfunction or other set of circumstances in the DSS operation, which requires immediate attention.
Explosable Items	Any item containing a non-compensated volume which has the potential for failure under internal pressure.
Fire Resistant	A material that will immediately self extinguish when the source of ignition is removed, when tested in an atmosphere representative of its intended use environment.
Flotation System	The materials, tanks, piping, components, or equipment that provide buoyancy to the DSS as may be applicable.
Foundation	That permanently installed part of a DSS which serves exclusively to support the DSS.
Framing System	(See Hull Structure)
Handling System	That system or subsystem of the DSS which is used in storing, deploying, operating and retrieving the DSS and is intimately related to safety of DSS personnel.
Hard Structure	Pressure resistant structures including reinforced openings and penetrations, but other than the pressure vessels, which may experience high differential pressure and that are designed to the same criteria as the pressure vessel. (e.g. buoyancy or variable ballast tanks)

Heat Resistant	A material that does not give off noxious fumes at its operating temperature or at any temperature below 200 degrees Fahrenheit and which is not degraded in respect to performing its intended function when exposed to a temperature of 400 degrees Fahrenheit for 5 minutes.
Hull Structure	Non-pressure structure which will not experience differential pressure, (e.g. floodable structure supporting equipment and including hydrodynamic fairing). For shore based facilities the appropriate term is Framing Systems.
Hyperbaric Chamber	Pressure-resistant structure, including pertinent reinforced openings, penetrations, and hatches, which experiences high differential pressure and which provides space for personnel.
Hyperbaric Facility	A complex, for operation at pressures above atmospheric, in which the magnitude and rate of change of the pressure and the composition and temperature of the confined atmosphere and/or water can be accurately controlled.
Implodable Items	Any item containing a non-compensated compressible volume which has the potential for failure under external pressure.
Life-Support Systems	A system that provides a livable environment (see paragraph 2.4.4).
Material Adequacy (materially adequate)	Designed and constructed of the proper materials and performance tested in accordance with accepted engineering principles so as to provide for the safety of the DSS personnel.
Milestone Event Schedule	A list of sequential events in the certification process with estimated completion dates.
Non-combatant	A DSS which, by its design, is incapable of defensive or offensive action in combat.
Occupant(s)	Any person occupying the DSS.
Operator(s)	<ol style="list-style-type: none"> 1. The organization, agency, or firm having responsibility for the operations, repair and maintenance of the DSS. 2. The personnel who physically control the operating parameters of the DSS.
Passenger(s)	Any person embarked who is not involved in primary control of the DSS.

Penetration	The assembly, component, shaft packing gland, seal, or other device which penetrates the pressure resistant structure (e.g. pressure vessel or hard structure).
Pressure Vessel	See definition of Hyperbaric Chamber.
Pre-Survey Outline Booklet (PSOB)	A check list that identifies those areas to be reviewed as part of the certification procedure for a specific DSS.
Procedural Adequacy	The procedures used in the operation and maintenance of the DSS are suitable and sufficient to provide for the safety of the occupants and operators of the system, before, during or after any credible operational/emergency evolution.
Procedures	Instructions, checklists, and maintenance guides prepared in a manner that provides to the occupants and operators a detailed safe sequence of operations of the DSS in all its various designed normal and emergency operating modes.
Recordable Evidence	All recorded information, including operational and maintenance procedures which can be used as proof that the DSS has been designed, constructed of the proper materials, fabricated, assembled, and performance tested in accordance with acceptable engineering principles.
Repair	A restoration or replacement to the original condition which does not change the original design material, configuration or performance, using procedures previously approved.
Replacement-in-Kind	Replacement with parts or components meeting original specification requirements.
Scope	See Certification Scope.
Sponsor	See Applicant/Sponsor.
Submersible	Any ship, vessel, capsule or craft capable of operating underwater, with or without propulsion with the operators and/or passengers embarked.

Survey

To examine, inspect and review in detail all items falling within the certification scope to determine their material adequacy and procedural adequacy.

Survey Team

The personnel representing the Navy to perform the onsite verification survey of the DSS.

System Certification

The procedure including application, independent technical review, survey and approval to insure the adequacy of the DSS to safely perform over its operational/emergency spectrum. System certification is a combination of two major areas of review; material adequacy and procedural adequacy. (This replaces the old term "material certification.")

System Certification
Authority (SCA)

The code within either NAVSHIPS or NAVFAC, as applicable, that has been delegated, through the Navy chain of command, the responsibility to conduct the Deep Submergence System Certification process.

1.3 PURPOSE

The purpose of this manual is to describe the process for determining that a DSS, on which the lives and well-being of Naval personnel is dependent, is adequate from a safety standpoint. This process extends to the determination of system adequacy within the operational limits for which certification is being requested. It is not intended to restrict the development or use of new ideas, systems, hardware, or equipment.

The basis for determining the system adequacy of each DSS will be the information and justification submitted by the Applicant/Sponsor. This manual describes the procedures and criteria that will be used by the System Certification Authority and which should be considered by the Applicant/Sponsor.

1.4 APPLICABILITY

System Certification is required for any DSS built by the Navy, or built by private industry and used by the Navy under contract, and/or built by private industry and subsequently purchased by the Navy for use by Naval personnel. If the lease or charter of the DSS does not involve the safety of Naval personnel, the DSS need not be certified by the Navy.

This manual covers System Certification of all types of manned DSS capable of operating with or without propulsion, on and under the surface of the water or land based with the operator(s) and/or passengers embarked in a wet or dry environment and which, by its design, is incapable of either defensive or offensive action in combat. Typical examples are grouped as follows:

Groups:

I Man is dry; always at one atmosphere except when in escape trunk

Examples:

- (a) Untethered submersibles such as TRIESTE, Deep Submergence Rescue Vehicle (DSRV), ALVIN, TURTLE, DEEP VIEW, etc.
- (b) Tethered chambers such as bathysphere, McCann Submarine Rescue Chamber, acrylic elevator, etc.
- (c) One atmosphere SEABED Habitats.

II Man is dry; capability for elevated pressures

Examples:

Hyperbaric chambers, recompression chambers (such as single and double lock recompression chambers, collapsible recompression chambers), deck decompression chambers, entrance locks, medical chambers, etc.

III Man is wet; capability for elevated pressures

Examples:

- (a) Diving equipment and integrated systems on the man such as hardhat gear, mixed gas scuba (MARK 6, MARK 8, MARK 10, MARK 11, etc.)
- (b) Submarine escape apparatus such as Steinke Hood, exposure suits, or other escape breathing apparatus.

IV Man is wet or dry; pressure is elevated

Examples:

- (a) Manned underwater habitats such as MAKAI Habitat, SEALAB and TEKTITE. (The habitat may or may not be pressurized as a step in the implantment evolution, but design is basically for free communication between habitat and the sea.)
- (b) Saturation Deep Diving Systems such as DDS MK 1, DDS MK 2, etc.
- (c) Shore based hyperbaric facilities such as the Navy Experimental Diving Unit (FNU) and the Ocean Simulation Facility (OSF) Panama City, Florida.

For each DSS, the basis for System Certification will be the evaluation of the recordable evidence submitted by, or in the custody of the applicant and such on-site surveys and audits which are deemed necessary by the SCA. The recordable evidence should encompass the areas of:

- (a) Design
- (b) Construction, Fabrication and Assembly
- (c) Quality Assurance
- (d) Testing
- (e) Operability
- (f) Maintainability

For a new DSS, the assembly and presentation of this recordable evidence to the SCA should require a minimum of time and effort. It is no more than that information normally expected to be generated by a prudent designer and builder.

For a new DSS, which is an exact duplicate (e.g., depth limits, temperature, period of use, environment, etc.) of a certified DSS, an audit of the quality control and testing records and a survey of the DSS may provide sufficient recordable information.

For a DSS already in existence and possibly in service, the assembly of sufficient recordable evidence might require considerable effort. If recordable information is not

easily recapturable, the information may have to be re-created. To re-create recordable evidence, the applicant may have to resort to non-destructive and/or destructive testing, inspection and design review analyses.

The criteria noted in this manual will not necessarily cause the System Certification of current tenures to be revoked prior to normal expiration. However, all recertification shall be judged using the criteria established by this manual.

It must be recognized that information may become available that indicates the existence of an unsafe condition which had not been previously identified. In such circumstances, when the SCA considers the severity of the condition to warrant such action, the design of all DSS, either certified or still in the certification process, will be reevaluated with respect to the unsafe condition.

1.5 SYSTEM CERTIFICATION PROCEDURE

The Navy activity that desires to lease or purchase an existing commercial DSS for use by Naval Personnel should include system certification requirements for DSS as elements of the contract.

The organization within the Navy that is contracting for the design and/or construction of a DSS should translate system certification criteria and documentation considerations (to support a System Certification Technical Review) into the contract specifications. The use of this manual as a contract reference document, with contractor interpretation of requirements should be avoided. (Note: If a contractor anticipates lease, or purchase by the Navy, of a DSS he is building, he should become familiar with the documentation requirements necessary to support a system certification technical review.)

The Naval Activity utilizing an existing Navy DSS should initiate System Certification Procedures in accordance with the current OPNAVINST 9290.2 series, prior to continuing DSS operations.

1.5.1 Procedure

The System Certification Procedure normally will include the following steps:

(a) The Applicant/Sponsor should prepare a System Certification Application in accordance with the provisions of Chapter IX which includes the following:

- (1) Preparation of a System Certification Scope, as outlined in Chapter II, and a Certification Milestone Event Schedule for negotiation and approval by the System Certification Authority (SCA). The certification milestone event schedule should include a list of sequential events in the Certification process with estimated dates of completion. The time allowance for documentation submittals, technical reviews, and deficiency corrections should be considered in the milestone event schedule to assure a timely completion of the certification process prior to the desired use date.
- (2) Preparation of a Pre-Survey Outline Booklet (PSOB) based on the system certification scope for negotiation and approval by the SCA. The PSOB should be tailored to the particular DSS from a typical PSOB format.

b. The applicant/sponsor will be required to provide funds, based on the SCA's cost estimate, to support the documentation review, survey team travel expenses and other certification related expenses as determined from the scope, PSOB and milestone event schedule.

c. The applicant/sponsor should collect the documents that support each line item of the PSOB, index them to the PSOB line items and submit them to the SCA. A documentation index list should also be maintained by the applicant for reference.

d. The SCA will perform the Documentation Technical Review and Evaluation and will inform the applicant of deficient items or insufficient recordable evidence prior to the DSS on-site survey to allow corrections.

e. The SCA will conduct an on-site survey, as discussed in Chapter VIII, to determine design compliance and assure the adequacy of the DSS for manned dives up to the limits to which Certification is being requested.

f. The SCA will, following the on-site survey, participate in an operational demonstration to the limits to which certification is being requested.

g. A certificate of System Certification will be issued by the SCA after the successful completion of the operational demonstration and the correction of deficiencies recognized at that time.

h. The applicant/sponsor is thereafter responsible for Sustaining System Certification, Continuance of System Certification, or Recertification. (See Chapter X for guidance.)

Figure 1-1 presents a flow chart of the System Certification Milestone Events. The applicant and SCA interplay and negotiations between milestones is stressed. Effective and frequent communication can avoid delays in planned schedules and reduce the overall effort for the applicant and SCA.

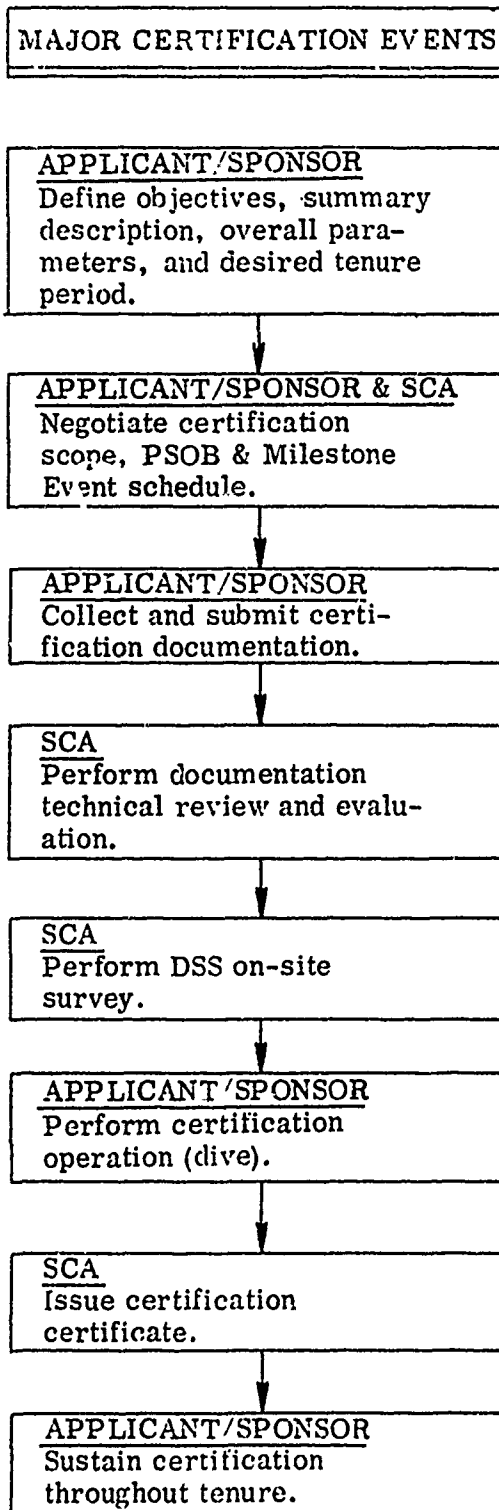


FIGURE 1.1 FLOW CHART, SYSTEM CERTIFICATION MILESTONE EVENTS

CHAPTER II

SYSTEM CERTIFICATION SCOPE

2.1 INTRODUCTION

The system certification scope includes the pressure boundary, materials, equipment, systems and operating procedures needed for safe operation and to recover from a malfunction or accident and above all, a system for sustaining life which will permit recovery of the operators, divers, or occupants of the DSS without unduly imperiling their health or well being.

This Chapter provides guidelines for defining those critical areas, components and systems of a DSS which must be considered for System Certification. Most accidents result from a series of events beginning with a single failure, often relatively minor, which may place the DSS Personnel or equipments under additional stresses. The avoidance or prevention of such initial failures in the normal operation of equipment enhances the overall safety of the DSS.

The philosophy of certification is, therefore, only to consider recovery from a single failure. Based on this philosophy systems and components may be determined to be critical or non-critical.

2.2 SYSTEM CERTIFICATION SCOPE

The applicant shall submit to the SCA, for negotiation leading to ultimate approval, a detailed list of all portions of the DSS and its ancillary equipment which, in the applicant's best judgement, fall within the system certification scope as defined in 2.3. Illustrative examples of such systems and characteristics are given in 2.4. In addition, the applicant should include the criteria and supporting justification for limiting the specific scope submitted. Those portions of the DSS that fall within the certification scope should meet all applicable requirements discussed elsewhere in this Manual. Non-scope portions and systems may be reviewed by the SCA for their contributions to the overall safety of design. Statements in this Manual pertaining to non-scope areas are for guidance only.

2.3 DEFINITION OF SYSTEM CERTIFICATION SCOPE

The System Certification Scope of a DSS is a list of those systems required to insure and preserve the safety and well-being of its operators, divers, or occupants. It encompasses "life critical elements" of all systems, subsystems, components and portions of the DSS including normal operating and maintenance procedures which are needed to insure the continuous physical well-being of the operators, divers, or occupants. It also encompasses those emergency systems and procedures required to return them safely from any depth, down to the maximum operating depth, back to the surface or to a submerged base under abnormal conditions following any non-catastrophic accident or casualty which precludes continued normal operation of the DSS.

Components, systems, and portions of the DSS that require certification include:

- a. All components, systems and portions of the DSS which, through malfunction or failure could prevent the return of the DSS operators, divers, or occupants to the surface or to a submerged base.

b. All components, systems and portions of the DSS required to keep operators, divers, and/or passengers safely on the surface following any ascent.

c. All components, systems and portions of the DSS provided to rescue personnel from the DSS and return them to the surface, support ship, a submerged base; or, in the case of hyperbaric chambers, to ambient conditions outside the chamber.

d. All systems and components including temporary test equipments affecting trim and stability conditions, both surfaced and submerged, which could prevent the safe recovery of personnel from a DSS.

e. Normal and emergency operating procedures.

f. Maintenance procedures.

2.4 EXAMPLES OF AREAS OF A DSS INVOLVED IN SYSTEM CERTIFICATION

It is recognized that individual DSS designs will vary to the extent that no single list can adequately define the system certification scope for all cases. The following list of areas which could require certification is given for purposes of illustration and should not be considered all inclusive or universally applicable.

a. The pressure hull, pressure vessels, hard structure and appurtenances.

b. The ballast systems which can be used for maintaining adequate freeboard when operating a submersible capsule or habitat on the surface or that can be used for emergency surfacing.

c. Jettisoning and emergency blow systems which can be used to return the DSS to the surface in the event of an emergency.

d. Normal and emergency life support systems which provide an acceptable atmosphere to the DSS personnel.

e. Non-compensated equipment, subject to pressure, which may implode or explode (see Appendices C and D).

f. Release devices for external appendages.

g. Fire fighting devices or systems.

h. Communication systems that enable personnel utilizing the DSS to communicate with support personnel.

i. Monitoring/detecting devices which will be depended upon to assure that the DSS does not exceed specified limits.

j. Obstacle avoidance systems, such as active sonars, fathometers, passive sonars, TV viewing systems, optical viewing devices and periscopes.

k. In the case of a submersible, the propulsion system may be included when the submersible operates under or near overhangs, cliffs, canyons, etc.

l. Accessibility to vital equipment which actuates recovery systems or is involved in life support systems. These should include systems which may be required for recovery of personnel from the DSS following a casualty.

m. Flotation or buoyancy systems whose failure or inadequacy could prevent the return of the DSS personnel to the surface.

n. Electric power systems which include internal and external electrical protective devices whose failure could result in malfunction of a critical component or system.

o. Written operating and maintenance procedures including pre- and post-dive procedures for the particular DSS.

p. Support ship handling system components such as cranes, brakes, and cables when the DSS is handled with personnel aboard.

q. Components, systems, and portions of the DSS that protect the DSS personnel directly or indirectly against the effects of accidents and hazards.

r. The diver-carried equipment, which includes the systems, subsystems, components, and portions of the equipment located on the diver side of the umbilical or supply hose connection required to insure and preserve the safety and well-being of the diver, such as:

(1) Diver's breathing gas systems, materials and their applications, valves and regulators, breathing gas containers, carbon dioxide absorbers.

(2) Diver's headgear, face masks, mouthpieces, helmets.

(3) Diver's breathing gas hose, umbilicals, gas fittings, connectors, fasteners, and clothing.

(4) Diver's instrumentation, sensors, and alarms.

(5) Diver's electrical systems, communication systems, navigation systems, and heating systems.

s. Systems which provide control of the diver's body temperature and subsystems and components that protect the diver against accidents and hazards in the underwater environment.

t. Systems located on the gas supply side of the diver's umbilical or supply hose.

2.5 PRE-SURVEY OUTLINE BOOKLET (PSOB)

Upon approval of the negotiated certification scope by the SCA, a PSOB is to be prepared by the applicant. The PSOB is a detailed checklist that utilizes the certification scope as the index and expands each scope item with typical requirements for recordable evidence, such as:

a. Design parameters

b. Design calculations and analyses

- c. Material evaluations
- d. Verification by model testing
- e. Review of as-built drawings
- f. Review of fabrication and inspection procedures
- g. Material traceability
- h. Review of NDT results
- i. Proof tests
- j. Surveillance program
- k. Material survey

There are five PSOB guides presently available from the SCA . aid the applicant.
These are:

- (1) NAVSHIPS 0900-028-2020 "Pre-Survey Outline Booklet for Manned Non-Combatant Submersibles."
- (2) NAVSHIPS 0994-009-7010/NAVFACP-422.1, "Hyperbaric Facilities, Pre-Material Certification Checklist."
- (3) NAVSHIPS 0994-013-7010, "Pre-Survey Outline Booklet for Diver Equipment."
- (4) NAVSHIPS 0994-014-0010, "Pre-Survey Outline Booklet for Standard U.S. Navy Recompression Chamber Installations."
- (5) NAVSHIPS 0994-014-9010, "Pre-Survey Outline Booklet for Standard U.S. Navy Surface Supp ted Diver Equipment Systems."

The line items of these PSOB guides are pre-printed in a format that follows a typical scope of certification and includes typical requirements for recordable evidence. The applicant should tailor his PSOB guides to his particular submersible, hyperbaric facility, or diver equipment by checking the applicable items. Items which are not covered by the PSOB but are judged to be applicable, due to their relationship to the system, should be added on the additional sheets provided.

For other DSS, the applicant may wish to tailor the submersible PSOB for the submersible elements of the system (i.e., PTC, habitat) and the hyperbaric facilities PSOB for the deck elements (i.e., decompression/recompression chambers, handling system).

After the PSOB is approved by the SCA, the applicant should use it as a checklist for assembling the supporting recordable evidence. Documentation submitted by the applicant should be indexed to the PSOB item number to facilitate its technical review.

normal or casualty operations such as explosively jettisoning external equipment; (d) from collapse of any non-pressure-compensated elements.

- (12) Fatigue load life of the pressure resisting components and piping for a specified number of cycles in a cold seawater environment.

c. Drawings

The applicant should submit up-to-date copies of drawings of each component and system evaluated in the design analysis. These drawings, showing all critical dimensions and tolerances relevant to performance, should be the actual drawings used for manufacture and fabrication. Each component or item on a drawing should be identified by the manufacturer model or type number, vendor identification, applicable Military Specification, Federal Specification or Standard as appropriate.

3.3.4 Operability and Maintainability Criteria and Procedures

a. Operability Analyses

The applicant should submit the analyses used to evaluate the operability of the DSS. Such analyses normally include an information flow diagram, an operational sequence diagram, a human engineering analysis of the instrumentation and control layouts, and an analysis of the life support monitoring and control systems. Included also should be an analysis of the various emergency modes of operation to assure that the design reflects the needs of these special conditions.

b. Maintainability Analyses

The applicant should submit the maintainability analysis used to develop the maintenance philosophy and general maintenance procedures. The analysis should show that the design permits rapid positive identification of malfunctions, and rapid isolation and repair of the faulty items by assigned DSS personnel.

c. Criteria and Procedures

The criteria and procedures upon which operation and maintenance are based should be explained. Human engineering factors and emergency procedures should be included.

d. Replacement Parts

Critical parts for replacement "in kind" should be readily available. Standard parts are preferred to those available only on special request. Replaceable equipment should be designed so that incorrect installation is prevented.

e. Manuals

Operating and Maintenance Manuals are to be identified. The contents of these manuals, as they affect safe operation, will be considered in the certification process. (See Chapter VII.)

3.3 DESIGN REVIEW INFORMATION

Design review information should be submitted by the applicant for review. The information should include at least the following:

- a. System Certification Scope - 3.3.1
- b. Summary Description of DSS - 3.3.2
- c. Design Parameters - 3.3.2.a
- d. Subsystem Descriptions - 3.3.3.b
- e. Design Analysis - 3.3.3
- f. Operability and Maintainability Criteria and Procedures - 3.3.4
- g. Material Justification - 3.3.5
- h. Toxic and Flammable Materials - 3.3.6
- i. Atmospheric Analysis - 3.3.7

3.3.1 Certification Scope

The Certification Scope, described in Chapter II, should be stated.

3.3.2 Summary Description of DSS

The applicant should submit a summary description of the DSS to facilitate the evaluation of the safety of the DSS. This summary should include a mission profile or dive scenario. There should be a written explanation of the features of the DSS with appropriate schematic drawings to show the relationship of various systems and equipment used to accomplish operational functions (see Paragraph 2.4.)

a. Design Parameters

The design parameters of the system must be identified. These design parameters will provide the basis for evaluation of the adequacy of the design for system certification. General design parameters which are recommended for consideration by the applicant and which may be evaluated by the SCA include:

- (1) Type of life support equipment
- (2) Displacement/Volume/Manning Requirements
- (3) Design safety factors
- (4) Design life and service period
- (5) Effect of ambient operating conditions and mechanical shock/vibrations on design life
- (6) Replacement or replenishment requirements

- (7) Depth/Pressure limitations
- (8) Correlation with the mission profile (scenario) including supply requirements to support the maximum duration of mission
- (9) Limits for breathing-gas composition, pressure and flow, temperature, and humidity
- (10) Specification and justification of breathing gas contamination limits
- (11) Temperature limits for both normal and emergency operating conditions
- (12) Thermal protection requirements
- (13) Hazards
- (14) Other physiological considerations
- (15) Failure modes and effects concepts
- (16) Emergency equipment requirements and capabilities
- (17) Communications requirements

b. Subsystem Descriptions

Each subsystem within the certification scope should be described. These subsystems should include the fluid systems, the electrical systems, compressed air and gas systems and significant mechanical and structural features. Each subsystem design should, as a minimum, be submitted with both a written description and function/flow diagram. The subsystem description should clearly delineate objectives of the design and safety considerations. An analysis of the consequences of a failure or loss of normal mode should be included. The diagram should show clearly how the subsystem accomplishes its intended function. Sufficient information should be included to identify the specific components and their location, orientation, size, bill of material, etc.

Note: Failure mode analyses should be performed sufficiently early in the design process so that they may influence the detail design to develop suitable reliability, to insure safety of the personnel, and to indicate required redundancies.

3.3.3 Design Analysis

a. Design Calculations

Where design calculations are submitted to demonstrate the adequacy of design, the calculations should clearly state all assumptions and rationale used in the analysis. The calculations should indicate the effect of worst case drawing dimensions and tolerances or "as-built" dimensions. Potential corrosion should also be considered. Appropriate reference should be made either to applicable test data or to operating experience when they are used to support a calculation technique. The design calculations should clearly show, in an orderly manner, the adequacy of the item analyzed in terms of the design parameters of the DSS. Information should be submitted in sufficient detail to permit independent analysis of the design. Documentation submitted by the applicant

should be tabulated to assure that the information completely covers the design. The documents should be also indexed to the PSOB to facilitate the technical review.

b. Stress Analyses

The applicant should demonstrate that the design is satisfactory by means of detailed stress analyses and the appropriate tests as described herein. Test programs performed by the applicant in support of system certification should cover the effects of all stress analyses considerations.

Stress analyses and test reports submitted by the applicant should also consider the worst loading case which includes the cumulative detrimental effects of design allowances, dimensional variations and tolerances.

Examples of loads to be considered are:

- (1) Weight of water used for hydrostatic testing.
- (2) Forces encountered while transporting, securing, removing, or handling the DSS or components thereof.
- (3) Static loads imposed by the clamping or securing means used to secure the DSS.
- (4) Normal operating pressure of gas within the DSS.
- (5) Thermal stresses due to the normal operating temperatures of the DSS.
- (6) Reactions due to differential thermal expansion of the DSS and the structure to which it may be fixed, or due to elastic expansion of the DSS caused by internal pressure.
- (7) Vibration transmitted from a ship or aircraft which may be transporting the components of the DSS.
- (8) Shock, including accidental blows.
- (9) In the case of portable chambers,
 - (a) Forces developed while hoisting, transshipping or transporting the chamber while pressurized to a specific pressure. Accidental dropping through a specified reasonable distance (such as 3 or 4 in.) while pressurized to a specified pressure.
 - (b) Reactions due to clamping or securing to an irregular base. Minimum qualifications for a base may be specified as a design parameter and, if so, should be cited in the Operating Manual as a system limitation or precaution.
- (10) Forces developed by shipboard accelerations imposed by ship motions.
- (11) Dynamic loads such as those encountered when: (a) launching, retrieving, or handling certain DSS; (b) bottoming a DSS at normal rate of descent; (c) in

normal or casualty operations such as explosively jettisoning external equipment; (d) from collapse of any non-pressure-compensated elements.

- (12) Fatigue load life of the pressure resisting components and piping for a specified number of cycles in a cold seawater environment.

c. Drawings

The applicant should submit up-to-date copies of drawings of each component and system evaluated in the design analysis. These drawings, showing all critical dimensions and tolerances relevant to performance, should be the actual drawings used for manufacture and fabrication. Each component or item on a drawing should be identified by the manufacturer model or type number, vendor identification, applicable Military Specification, Federal Specification or Standard as appropriate.

3.3.4 Operability and Maintainability Criteria and Procedures

a. Operability Analyses

The applicant should submit the analyses used to evaluate the operability of the DSS. Such analyses normally include an information flow diagram, an operational sequence diagram, a human engineering analysis of the instrumentation and control layouts, and an analysis of the life support monitoring and control systems. Included also should be an analysis of the various emergency modes of operation to assure that the design reflects the needs of these special conditions.

b. Maintainability Analyses

The applicant should submit the maintainability analysis used to develop the maintenance philosophy and general maintenance procedures. The analysis should show that the design permits rapid positive identification of malfunctions, and rapid isolation and repair of the faulty items by assigned DSS personnel.

c. Criteria and Procedures

The criteria and procedures upon which operation and maintenance are based should be explained. Human engineering factors and emergency procedures should be included.

d. Replacement Parts

Critical parts for replacement "in kind" should be readily available. Standard parts are preferred to those available only on special request. Replaceable equipment should be designed so that incorrect installation is prevented.

e. Manuals

Operating and Maintenance Manuals are to be identified. The contents of these manuals, as they affect safe operation, will be considered in the certification process. (See Chapter VII.)

3.3.5 Material Justification

The applicant should justify the materials and their applications as used in the design of the DSS for the expected service environments. All of the materials considered to be within the certification scope should be identified. The relative location of the materials should be included and verification of their compatibility with adjacent materials should be provided where electrolytic corrosion or other material incompatibility problems are a concern.

It is anticipated that some DSS will be designed to operate at greater depths and that new materials, new applications for time tested materials, and new configurations may be employed. It is not the intent of this manual to limit the materials and their applications. The intent is to permit the use of new materials or materials in new applications whenever sufficient data exists to show that the material adequacy of the DSS, and hence the safety of the personnel utilizing the DSS, is reasonably assured. The less the amount of available information and experience with a material or application, the greater the burden upon the applicant to justify the adequacy of the proposed material or application. For the purpose of System Certification the possible materials and/or components are grouped into the following three categories:

a. Category 1.

Materials and components with which there is both considerable fabrication experience and also considerable operating experience in the intended environment and application.

b. Category 2.

Materials and components which have not been used extensively in similar applications but are classed as conventional due to identification by Military Specifications, Federal Specifications, or recognized American Commercial Standards such as those published by the American Society of Mechanical Engineers or the American Society for Testing and Materials. Materials or components available as standard stock items built to a recognized commercial or Federal standard will be considered in this category. Examples of materials and components that are presently considered to be in this category are certain types of aluminum, titanium, and some high and low strength steels. The determination of acceptable properties and allowable operating stress values will be based on the recommendations and supporting information provided by the applicant.

c. Category 3.

Materials and components for which definitive information and experience are not available. The basis for testing and the criteria for acceptance of new materials and components will not automatically be the same as for those currently in use. The proof of acceptability of the material or component and justification of the acceptance criteria must be provided by the applicant. THIS MANUAL NEITHER SPECIFIES ACCEPTANCE TESTS FOR NEW COMPONENTS OR MATERIALS NOR ARBITRARILY DEFINES ALLOWABLE OPERATING PARAMETERS. For example, the applicant should demonstrate the effect of defects, manufacturing tolerances and production variations upon the reliability of the material or component by appropriate model and/or prototype testing in a simulated service environment. The applicant must establish that the new material or component possesses at least the same factor of safety as is provided by proven materials in a similar application.

As a minimum the applicant should submit the information required in Appendix A for the justification of Category 3 items.

3.3.6 Toxic and Flammable Materials

The applicant should submit a list of all potentially toxic and/or flammable materials used in construction and fabrication and installed in the DSS. Toxic materials may be paints, insulation, adhesives, sealants, lubricants, equipment, instruments, fittings or other items that could give off noxious fumes at their operating pressure/temperature or at any temperature below 200°F. Flammable materials include materials in a form which will ignite or explode from an electric spark or from heating and which, if so ignited, will independently support combustion in the presence of air or in any oxygen enriched atmosphere that may be encountered in the DSS under either normal or emergency conditions.

3.3.7 Atmospheric Analysis

Prior to manned use of the DSS an analysis of the DSS atmosphere must be submitted for review. (See Appendix F).

CHAPTER IV

CONSTRUCTION, FABRICATION AND ASSEMBLY

4.1 INTRODUCTION

This chapter describes the documentation the applicant should submit to the SCA concerning construction, fabrication, and assembly processes that affect performance of the DSS. This documentation should include supplementary information such as work procedures, heat treating instructions, welding procedures, in-process inspection procedures, assembly procedures and clean room procedures that are needed to accomplish the construction and also whether or not such process information is specifically identified or referenced in the design drawings.

4.2 RECORDABLE EVIDENCE

The information submitted by the applicant relative to construction, fabrication and assembly processes should include the following:

- a. Identification of the construction, fabrication and assembly process that affect design performance.
- b. Inclusion of the process documents.
- c. Substantiation of the adequacy of these processes based on previous use history or based on process qualifications and tests.

4.3 CONSTRUCTION AND FABRICATION PROCESS REQUIREMENTS

In addition to the process evaluation required in 4.2 above, the applicant should also comply with the following requirements.

4.3.1 Welded Construction

All welding should be done in accordance with written welding procedures which have been qualified. The welding procedures, procedure qualification requirements and welder qualifications should be utilized as controls over welding processes. The applicant is required to identify and/or submit the welding procedures used and make available for review, the procedure and the welder qualification records, as well as the results of the weld non-destructive tests. In addition, proof of fracture resistance of the weldment should be demonstrated by a test that is appropriate for the material selected. For example, a drop weight test or a drop weight tear test may be substituted for the explosion bulge test, where required. Repair involving heat or welding should be accomplished in accordance with specific requirements and subjected to, as a minimum, the tests and inspections specified for construction. Both personnel and procedures for repair must be qualified also.

4.3.2 Brazed Construction

All brazing should be done in accordance with written brazing procedures that have been qualified, and by brazers who have been qualified to perform the required brazing operations. The applicant is required to identify and/or submit the brazing procedures

used and make available for review the procedures and the brazer qualification records, as well as the results of the brazed joint non-destructive test.

4.3.3 Qualifications

The following welding and brazing procedures are typical of good qualification practices:

MIL-STD-00248 (Ships), "Welding and Brazing Procedures and Performance Qualification"

NAVSHIPS 0900-001-7000, "Fabrication and Inspection of Brazed Piping Systems"
ASME Boiler and Pressure Vessel Code, Section IX, "Welding Qualification"

4.3.4 Cleaning

It is recommended that the cleaning of breathing gas systems during assembly or fabrication be in accordance with an overall contamination control plan. System cleaning may be accomplished during assembly/fabrication, upon final completion of assembly, or a combination of both, at the option of the sponsor. The final levels of contamination must meet the requirements specified and justified by the sponsor and as accepted by the SCA. Refer to the Appendices F and G for guidance in cleaning and atmospheric evaluation.

CHAPTER V

QUALITY ASSURANCE

5.1 INTRODUCTION

The applicant should assure that quality assurance provisions are maintained which demonstrate that the DSS has been constructed in accordance with specified requirements. These quality assurance provisions should result in recorded evidence related to:

- a. Design and Drawing Control
- b. Material Control
- c. Fabrication, Manufacturing and Dimensional Control
- d. Testing and Inspection Control

Applying quality assurance provisions to all parts of the system in which failure can result in a hazard to DSS personnel will insure that the performance parameters of the system are achieved at the highest practical level of safety.

It is recognized that quality assurance provisions are more easily applied during construction of a DSS, however, it is none the less the responsibility of the applicant to establish means by which the quality of existing DSS may be evaluated.

5.2 QUALITY ASSURANCE PROVISIONS

Due to the life support nature of DSS, Quality Assurance and personnel safety are inseparable. All Quality Assurance considerations are in areas that also affect the safety of the operators, divers or occupants. These areas include, for example, initial forming, fabrication, assembly, cleaning, testing, inspection and preparation for delivery. The authority and responsibility of quality assurance personnel in each of these areas should be clearly delineated. (The aspects of Quality Assurance that the applicant should consider and justify in his request for system certification of the LSS are illustrated by, but not limited to, those mentioned.) Manufacturing, fabrication, and assembly work conducted within the DSS builder's plant should be carefully controlled. Such control should include a formal review and engineering evaluation of all manufacturing tolerances and deviations. An equally effective control over purchase materials and sub-contracted work should be provided.

An applicant for "Continuance of System Certification", or "Recertification" should demonstrate that an effective Quality Assurance Program will be (or has been) applied where repair, (other than simple installation of "in-kind" replaceable elements), alterations and/or overhaul are involved.

The applicant should maintain records and other data essential to the economic and effective operation of his quality control program. These records should be available for review by the System Certification Authority and copies of individual records may be required to be furnished on request. Records are one of the forms of objective evidence of proper quality control. The quality control program should be planned so as to insure that they are complete and reliable.

5.3 DRAWING CONTROL

The applicant should assure that current design drawings are promptly distributed to manufacturing personnel and that only current drawings are used. The applicant should show that his drawing control system requires approval of design changes, including material substitutions, before such changes are incorporated into the finished product. He should also show that his drawing control system requires removal of obsolete drawings and change requirements from all points of issue and use. The control system should also provide control over supplemental specifications, process instructions, production engineering instructions, industrial engineering instructions and work instructions that either implement the design or supplement design drawings to accomplish the manufacture and assembly of the DSS. The applicant should maintain the technical data and drawings required by the on-site survey team to determine whether or not the system certification scope items for the DSS correlate to the design.

5.4 MATERIAL CONTROL

For new DSS construction, the applicant should show that the program for material control is effective. The program should assure that materials used conform to the applicable physical, chemical or other technical requirements. A means of keeping track of the identity of tested and approved materials should be implemented. Controls should be established to prevent the inadvertent use of other than as specified material.

5.5 FABRICATION, MANUFACTURING AND DIMENSIONAL CONTROL

The applicant should show that the quality program assures that the DSS has been manufactured in accordance with the approved drawings and manufacturing processes. The applicant should also substantiate that required dimensional tolerances (such as thickness, mismatch, out-of-plane, out-of-round, sphericity, etc.) were achieved.

5.6 TESTING AND INSPECTION CONTROL

The applicant should show that there is an effective inspection system in effect that establishes the inspections and tests necessary to substantiate that the certification scope items of the DSS are in conformance with the requirements. The inspection system should incorporate clear, complete and current instructions for inspection and testing and should include criteria for approval and rejection. Records of all inspections and tests should be maintained that indicate the nature and number of observations made, the number and type of deficiencies found, the quantities approved and rejected and the nature of the corrective action taken.

The inspection system should verify that the latest applicable drawings, specifications and process controls, with all authorized changes incorporated, are used for fabrication, inspection and testing. The inspection system should describe the training and qualification of inspectors and should include demonstration of competence in techniques such as radiographic inspections and ultrasonic inspection. The inspection system should also provide for calibration of inspection equipment.

5.7 WORKMANSHIP

The hazards associated with the performance requirements of a DSS dictate the use of only high quality workmanship. Consequently, the evaluation of the workmanship evident in the finished DSS is a significant factor in determining the acceptability of the

individual DSS. Acceptance standards to establish high quality workmanship are difficult to specify. It is the responsibility of the prudent designer and builder to oversee the workmanship of the DSS to assure high quality.

5.8 QUALITY ASSURANCE INFORMATION

The applicant should submit information relative to the quality assurance provisions in sufficient depth and detail to permit audit and evaluation by the SCA. All quality control, inspection and material identification records should be retained, at a known location, throughout the system certification period. The system certification period will not be extended without the availability of such records.

CHAPTER VI

TESTING

6.1 INTRODUCTION

The applicant should develop and implement a test program which will demonstrate the adequacy of all systems and equipment within the certification scope. Pressure vessel strength, flotation and buoyancy systems, piping systems, emergency deballasting and jettisoning systems, life support systems (including breathing gas purity control), electrical insulation integrity and safety features are examples of items to be tested.

The test program for the DSS should be documented in the form of a series of test procedures. The applicant should provide both procedures and test data in order to obtain system certification. In general, tests required for system certification should be grouped in three categories:

a. Development Tests

This group covers those tests required to verify the design basis of the DSS. The performance of materials, mechanical designs and configurations, and systems which are unique or untried in a similar environment and are within the scope of certification must be demonstrated by such tests.

The tests to demonstrate the design basis of the DSS need not necessarily be performed on the actual DSS. In some instances, testing of a duplicate component may be appropriate. A further description of developmental material and structural testing requirements can be found in Appendix B.

b. Quality Assurance Tests

These tests are performed to demonstrate that the components, materials and fabrication of the DSS do, in fact, conform to design. They include such items as radiographic tests of welds, fabrication tolerance measurement, calibration tests, breathing gas purity tests, vendor's acceptance tests, etc.

c. Operational Tests

These tests are intended to confirm the capability of design, the operational characteristics and the operational procedures to be used with the DSS. For purposes of convenience, proof tests are handled as part of this category.

It is the purpose of the remainder of this chapter to describe the requirements for operational and proof testing.

6.2 GENERAL REQUIREMENTS FOR OPERATIONAL AND PROOF TESTS

The applicant should submit copies of all proof, pre-builder's or pre-sea trial test procedures and operational test procedures that are within the scope of certification to the SCA for information prior to conducting the tests.

The format of the test procedures should be such that both a test procedure and the data to be collected from that test will be contained in a single document.

As each step in a procedure (which requires that a component or system operate in a prescribed manner) is satisfactorily completed, this fact should be witnessed by the signature (or initials) of a representative of the builder's test or quality assurance organization. The date on which the step was performed should also be indicated. If the step requires that a particular parameter be within a specified range, both the required range and the actual value should be recorded.

Operational test procedures must be approved by the DSS designer.

Operational test procedures of the system for characteristics which are identified in the system certification scope must be reviewed by the SCA. A test schedule should be provided to allow witnessing those tests deemed critical by the SCA.

The SCA reserves the right to require a rerun of any or all of the operational tests if results are not clear or conclusive.

Upon completion of all operational testing, the SCA should be supplied with an indexed document containing copies of all completed operational test procedures indicating the results.

6.3 PROOF, PRE-BUILDER OR PRE-SEA TRIAL TESTS

Hydrostatic and/or pneumatic tests shall be performed on all components of the DSS within the system certification scope that are subjected to fluid pressure during operation. Pressure vessels, hard structure, penetration fittings, and piping should be tested in accordance with the parameters of Appendix B. A log of all joints should be maintained during the hydrostatic and/or pneumatic test and their satisfactory tightness should be indicated by inspector's initials and date. This log should be a part of the completed procedure.

A flush must be performed on all systems in which valve tightness or a motion of close fitting parts is required for the safe operation of the DSS. Such systems may include (but are not limited to) freeboard ballast system, trim and drain system, and hydraulic, gas, water, or air systems. Satisfactory completion of the flush will be achieved upon test verification of the degree of cleanliness as specified and justified by the designer.

Hydrocarbon oils, such as kerosene, shall not be used for hydrostatic testing of breathing gas systems. Corrosion inhibitors or other materials added to water used for hydrostatic testing shall be reported to the System Certification Authority by the applicant, and shall not leave toxic, noxious, flammable, or corrosion-inducing residues.

A cleaning procedure must be performed on all respiratory related life support and breathing gas systems. Such systems may include (but are not limited to) divers' breathing apparatus, hyperbaric chamber interiors, oxygen and diluent gas piping.

Satisfactory completion of the cleaning procedure will be achieved upon test verification of cleanliness and trace contaminant levels as specified and justified by the designer. See Appendices F and G.

The operation of any fire-extinguishing systems should be verified throughout the fire susceptible pressure range of the DSS. To reduce damage to delicate equipment, the demonstration of the fire extinguishing system prior to complete outfitting may be desirable.

The applicant should prepare and submit test procedures designed to demonstrate the adequacy of electrical insulation of any electrical circuits. These procedures should specify

not only the pass/fail criteria for the test, but also such test conditions as water temperature, pressure and length of exposure time.

All electrical cable, equipment and devices should be subjected to a dielectric strength test at 60 Hertz voltage for one minute. Military specifications specify dielectric test voltages. For other procurement specifications a test voltage of twice rated plus 1000 volts should be performed. The cable dielectric tests should be performed between all conductors and the sheath and also between conductors. This is a "go," "no-go" criteria test. Because of the destructive nature of a.c. dielectric testing this type testing should be limited to the manufacturer plant tests as part of procurement procedures or after a major overhaul of an equipment or device (e.g., a rewound motor). All subsequent insulation resistance testing should be with a d.c. potential. The d.c. voltage should not be less than 500 volts for electrical cables, equipment or devices. Insulation resistance measurements of all safety circuits excluding the actuating device should be made part of the pre-dive check-off list. A proposed log of the measurement readings should be submitted by the applicant. A log of periodic insulation resistance readings for all electrical systems and circuits is a valuable tool in planning maintenance and repair schedules. Humidity, contamination of insulation materials, accumulation of foreign matter on insulating surfaces and the length of cables have a bearing on insulation resistance values. Therefore, the change in insulation resistance values is of major significance. After being idle for a period, equipment and cables may exhibit lower than normal readings. However, after a time in operation the resistance may return to normal. This is an indication of moisture caused by high humidity. On the other hand, a steady gradual decline in insulation resistance is an indication of insulation contamination or collection of foreign matter on the insulating surfaces. One megohm is considered an acceptable value for all installed electrical systems. Any sizable drop from this value should be considered as a warning of impending failure. For personnel protection and safety 50,000 ohms is the lowest acceptable insulation resistance limit.

Static stability of the DSS must be demonstrated for all normal trim conditions. (This does not apply to fixed shore or shipboard hyperbaric facilities.)

Operating and casualty procedures for systems affecting personnel safety shall be performed. This should include a demonstration of the accessibility to vital safety equipment or systems to insure personnel can operate the equipment and systems under emergency conditions. Where an actual demonstration is not practical the applicant may propose alternate means of demonstrating the acceptability of the procedures. The satisfactory accomplishment of each step in each procedure should be initialed and dated by the responsible person in charge.

Tests should be performed with different gas supply pressures ranging from maximum to minimum to demonstrate that the design conditions of pressure regulation are attained. Pressure measurements should be made at each design level of pressure. Gas flow measurements should be made to demonstrate flow adequacy.

Maximum design gas pressure should be introduced into each part of the assembled DSS equipment and appropriate testing procedures should be used to demonstrate that the equipment is satisfactorily resistant to external leakage. Leakage acceptance criteria should be submitted to the System Certification Authority prior to the conduction of the tests.

Tests should be performed with different gas supply pressures ranging from maximum to minimum to determine the degree of internal leakage, if any, of gas pressure and flow control devices. Leakage acceptance criteria should be submitted to the System Certification Authority prior to the conduction of the tests.

Appropriate pre-operational test procedures should be submitted to the System Certification Authority for demonstrating the design performance of selected function of the DSS equipment. The tests should be grouped in two categories: equipment functions and operator/diver functions.

a. Test procedures should be formulated by the applicant to demonstrate the adequacy of the functions of selected equipment, subsystems and components. A typical subsystem could be the emergency gas system. A typical component could be a by-pass valve. These tests should be conducted with the fully assembled equipment unless special test fixtures are required.

b. Test procedures should be formulated by the applicant to demonstrate the acceptability of the functions required by the operator/diver to operate the DSS equipment. Typical operator/diver functions could consist of operation of the different valves and regulators under typical conditions, such as limited visibility. These tests should be conducted with the fully assembled equipment in place.

6.4 BUILDER'S OR SEA-TRIALS

All operating and casualty procedures not demonstrated in pre-builder trial testing shall be performed prior to final certification. Each step of each procedure should be initialed and dated when satisfactorily accomplished.

In the case of DSS that are being built for, overhauled, or otherwise acquired by the U.S. Navy, the following documents should be prepared and forwarded to the SCA by the sponsor/applicant to allow the trials to proceed prior to achieving system certification:

a. A statement that all deficiencies pointed out by the SCA on-site survey have been corrected and the DSS is satisfactory for the initiation of sea trials.

b. A statement detailing the trial schedule including a brief of the proposed trial agenda.

c. A statement of the anticipated area of operation reported by latitude and longitude, as applicable.

d. A description of general environmental considerations that have been given concerning safety (e.g., sea state limits, visibility limits, DSS handling capabilities, limits on diving under overhangs, cables, caves, etc.).

e. A statement of provisions for contractor and/or Navy surface support units.

f. A description of communication arrangements between the DSS and support units and between support units and shore.

g. A statement of rescue alternatives available.

A submersible DSS must be subjected to a test dive to the maximum depth at which it is to be certified to operate. Whenever possible, an unmanned dive prior to the manned dive should be accomplished. In achieving this maximum depth, the DSS must be maintained at a depth of approximately 100 feet before proceeding to deeper submergences. If the DSS is not designed to be maintained at a depth of 100 feet then an alternate method of achieving shallow depth inspection should be proposed. All joints and penetrations accessible from within the DSS should be inspected visually at this depth. All components, such as valves,

whose operation is subjected to submergence pressure and whose operation is required for safe operation of the DSS, should be operationally tested; welds, other joints and valves should be inspected; and the inspection results should be logged. The submergence should then be increased in increments of approximately 20% of the maximum operating depth until the maximum operating depth is reached. At each 20% increment, the DSS should achieve neutral buoyancy while the closures are reinspected and valves recycled. Unsatisfactory operation of a valve or unsatisfactory leak rate shall be cause for failure of the test. The test dive may be a single dive, as described, or a series of dives to accomplish the same purpose. A log of carbon dioxide, oxygen, temperature and pressure shall also be maintained. Readings should be taken at 30 minutes intervals or less.

A non-submersible DSS should also be subjected to an initial incremental pressurization with stops at appropriate pressures to cycle equipment and check for leakage.

The capability of all DSS power supplies in the system certification scope must be demonstrated to operate satisfactorily until they have met the designer's specified endurance.

The capability of the normal and emergency life support systems must be demonstrated to operate satisfactorily until they have met the designer's specified endurance.

The operation of the emergency deballasting or jettisoning systems should be demonstrated at-sea, where practicable. Where such operation may partially destroy the DSS, a simulated emergency deballasting or jettisoning test may be performed. Such a test simulation must be submitted for review to the SCA for approval of the concept prior to its accomplishment.

A means of releasing external appendages (e.g., boom mounted light and camera arrays, anchors, sample baskets, manipulators, etc.) should also be provided. The function of these devices should be to release in the event they become entangled or embedded so as to endanger the DSS. Testing the systems for satisfactory operations should be performed under adverse trim conditions, and where practicable should be performed at an "at-sea-demonstration."

All deficiencies noted during the test dive/pressurizations shall be corrected as directed by the SCA. Additional deep dives/pressurizations may be required as necessary.

Adequate instrumentation should be provided, where applicable, to measure the deformation and strain in the pressure vessel and where feasible in the section of the exostructure which supports vital devices in order that comparable data may be obtained in the process of the test dive to verify design calculations.

6.5 OPERATIONAL TESTS OF DIVER EQUIPMENT

a. The applicant should prepare and submit test procedures designed to demonstrate the operational characteristics of the diver equipment. These tests should be formulated to assist a diver in systematically demonstrating the operational characteristics of the diver equipment.

b. The operational tests should be performed by a diver acceptable to the System Certification Authority. The diver should prepare a written report on the operational characteristics of the diver equipment. This report should be a

part of the indexed document containing completed copies of all test procedures.

c. Upon completion of the operational tests a careful inspection should be made of the diver equipment, subsystems and components. This inspection is intended to verify that no condition has developed, as a result of the tests, which could be dangerous or which could impair the satisfactory operation of the diver equipment.

CHAPTER VII

OPERABILITY AND MAINTAINABILITY

7.1 INTRODUCTION

This chapter specifies the minimum requirements which the applicant should meet to assure the operability and maintainability of the DSS. Part of these requirements are covered in Paragraph 3.3.4, Operability and Maintainability Criteria and Procedures. In addition to the analyses, written procedures must be provided to cover normal and emergency operations, repairs and maintenance, and periodic inspections.

7.2 REQUIREMENTS

Written procedures are required for the following purposes:

- a. To insure that the normal operation of the DSS is within the safe operating conditions for which certification is requested.
- b. To insure that there are adequate corrective measures to cope with emergencies.
- c. To insure that there are check lists of prerequisites for various major evolutions (e.g., pre-dive and post-dive procedures, repairs and maintenance, and periodic inspections).
- d. To insure that information available for training of operators is consistent with safe operation of the DSS.

7.3 DEMONSTRATIONS

The adequacy of the normal and emergency procedures formulated by the applicant for operation of the DSS should be demonstrated to the SCA (see Chapter VI). Satisfactory accomplishment of each step in each procedure should be verified by initialing and dating by the SCA's representative. In cases where it is found that a procedure cannot be performed in a satisfactory manner, the applicant must prepare an alternate procedure for accomplishing the desired objective.

7.4 OPERATING MANUAL

- a. An operating manual or manuals should be provided describing all phases of DSS operation. As a minimum the following sections should be included:

- (1) System Description

This section should identify and describe the purpose and functional operation of all systems.

(2) Component Description

Sufficient design information should be included to identify and describe all major system components.

(3) Instrumentation and Controls

This section should discuss the control philosophy used in the system design and provide a detailed description of the controls and instrumentation used.

(4) Normal Operation

This section should identify all normal system operations and normal evolutions which involve personnel. Detailed, step-by-step, operating procedures for these normal operations and evolutions should be provided.

(5) Emergency Operation

This section should identify all conditions of emergency operation and provide procedures to be followed in the event of their occurrence. Emergency operation is defined as operation under conditions of system malfunction such as loss of power, component failure, physical damage, fire and in the case of diver equipment, loss of breathing gas pressure or flooding of breathing circuits.

(6) System Limitations, Precautions and Setpoints

In this section the applicant should clearly identify all DSS operational limitations. This section should also state all precautions to be taken during normal operation to preclude potentially unsafe conditions. A list of system operation setpoints which represent the normal operation of the system should be included. See Appendix E for Life Support System Limits.

(7) Operations Check Lists

The applicant should provide an operations check list which will be used to verify proper system alignment under all normal operating conditions. Check lists should identify the support equipment required to major operational evolutions, such as pre-dive preparations, diving, post-dive servicing, etc. A condition of certification of the DSS will be that the support equipment is operable and performing properly.

(8) Handling Operations

The applicant should provide handling procedures to cover any intended handling of the DSS such as during the air/sea interface penetration and mating. The procedures should, where appropriate, include details and precautions for handling, lifting, securing, break-down and reassembly of the DSS for transportation.

b. The operating procedures (normal and emergency) will be verified in the test program of the DSS to demonstrate that the procedures are satisfactory (see Chapter VI). Compliance with these procedures will be part of the system certification conditions. Any changes to the procedures must be submitted to the SCA for review.

7.5 MAINTENANCE MANUAL

a. "Sustaining System Certification" is predicated on maintenance of the DSS in the "as certified" condition. Accordingly, the applicant/sponsor should prepare a maintenance manual which should include, as a minimum, the following subsections:

- (1) Preventive maintenance including calibration and alignment of instrumentation and other equipment, as appropriate, in the DSS.
- (2) Corrective maintenance including repair and replacement of components.
- (3) System reentry procedures including post repair inspections and re-testing required to insure proper integrity and cleanliness of systems and equipment.

b. The applicant should provide instructions for conducting periodic inspection and tests to insure continued safe operation of the DSS. The instructions should include the scope of the inspection, tests and pass/fail criteria. These periodic inspections and tests will be a condition for "Sustaining Systems Certification." Specific periods for DSS overhaul should also be stated.

CHAPTER VIII

ON-SITE SURVEY OF DSS

8.1 INTRODUCTION

Upon completion of all testing, an on-site survey of the "as built" DSS will be made by the SCA. The purpose of the on-site survey is to determine, within the established certification scope, that the system, "as built," is in accordance with the technical package that was submitted for review.

8.2 SURVEY TEAM PERSONNEL

A survey team comprised of personnel representing at least the SCA and the sponsor/applicant will conduct the survey. The applicant should provide additional personnel as required to assist the survey team. Acceptability of survey personnel qualifications will be determined by the SCA.

8.3 SURVEY PROCEDURES

8.3.1 Survey Outline

The PSOB which has been used as a check-off list during the documentation technical review is further utilized as the survey outline. Line items of the PSOB which have not been satisfied earlier may be completed during the on-site survey.

8.3.2 Recordable Evidence

One of the main facets of the survey is the recordable evidence to support that the DSS is actually built as designed and that it will perform to the limits for which certification is being requested. Accordingly, the survey team will review recordable evidence in sufficient detail and depth to support a conclusion as to the acceptability of the DSS. The applicant should assure, prior to a survey, that necessary recordable evidence not previously submitted to the SCA is readily available for the survey team.

8.3.3 Extent

The survey in general will include a review of:

- a. The actual "as built" drawings used to construct the DSS.
- b. The drawing control procedures and records.
- c. The quality assurance system, quality control documentation procedures and records.
- d. The construction, manufacturing and assembly procedures and records.
- e. The construction, fabrication and assembly test procedures and records.
- f. The system proof and performance test procedures and records.
- g. The system cleaning procedures and records.

- h. The accessibility of vital equipment and components.
- i. The quality of workmanship in the DSS.

8.3.4 Evaluation

Upon completion of the survey, the SCA will forward the results of the survey team's evaluation of the DSS to the applicant for action. All deficiencies noted as "IA- must be accomplished prior to manned use" during the survey shall be corrected prior to further manned trials of the DSS. All deficiencies noted as "IB- must be accomplished prior to system certification" shall be corrected prior to issuance of the system certification. All deficiencies noted as "II-desirable" may be corrected at the sponsor's option.

CHAPTER IX

SYSTEM CERTIFICATION APPLICATION

9.1 INTRODUCTION

The purpose of this chapter is to assist the applicant in the preparation of an application for certification in accordance with the requirements of this Manual.

9.2 APPLICATION

The Naval activity desiring to utilize a fixed shore-based facility should apply to the NAVFAC SCA (NAVFAC 04B); all others should apply to the NAVSHIPS SCA (SHIPS OOC). An information copy should be sent to CNM (MAT 034). The application should state the following:

- General description of the DSS.
- Overall system parameters.
- Desired mission profile or dive scenario.
- Desired certification objectives defining the operational limits for which certification is being requested (i. e. pressure, temperature, time, sea-state, etc.).
- Desired tenure of certification.

The applicant should then identify the critical systems of the DSS and establish the following preliminary documents:

- Scope of System Certification
- Pre-Survey Outline Booklet
- Certification Milestone Event Schedule

These should then be negotiated with and approved by the SCA. On the basis of the approved version of these documents, the cost of the certification technical review and other related cost, such as travel expenses for the survey team, will be estimated by the SCA.

Utilizing the approved scope and PSOB as guides, the applicant should prepare and submit the following documentation in a timely manner to meet the milestone event schedule:

- Design Review Information - See Chapter III.
- Construction, Fabrication and Assembly Information - See Chapter IV.
- Quality Program Information - See Chapter V.
- Test Program Information - See Chapter VI.
- Operating and Maintenance Procedures - See Chapter VII.

This information should not be considered to be all inclusive. Additional information may be required in the course of certification to fully justify areas of concern. (See "Pre-Survey Outline Booklet" for the respective DSS for the general types of recordable evidence desired.)

After 80% or more of the documentation has been reviewed an on-site survey will be scheduled. A favorable survey will permit commencement of a certification operational demonstration to the depth/pressure limits as stated in the certification request. The certification operational demonstration may be conducted in conjunction with other Navy program requirements (i.e. INSURV Inspection, OPEVAL, etc.). Favorable completion of the certification operational demonstration and review of the remaining documentation will justify the issuance of a System Certification.

CHAPTER X

TENURE OF SYSTEM CERTIFICATION

10.1 INTRODUCTION

The purpose of this chapter is to outline the various conditions which follow granting of System Certification. The granting of System Certification by the SCA does not automatically ensure that System Certification will remain effective for the full certification period. System Certification SHALL NOT be granted for the entire design life of the DSS. In general, the time period for which System Certification will initially be granted (Tenure of System Certification) is based on the DSS mission profile (scenario) and operating and test histories of related systems. The tenure of System Certification may be negotiated to coincide with planned events such as overhaul, refurbishment, etc. System Certification shall be terminated as a result of the following:

- a. Major Overhaul or repair
- b. Expiration of a lease contract
- c. Broaching of the scope of System Certification
- d. Expiration of tenure of System Certification
- e. Recognition of the existence of an unsafe condition

10.2 SUSTAINING SYSTEM CERTIFICATION

"Sustaining System Certification" is the action required to assure the SCA that the DSS remains in the "as certified" condition for the period of certification. As was noted above, granting System Certification by the SCA does not automatically ensure that System Certification will remain in effect for the full certification period. The responsibility for "Sustaining System Certification" during the certification period falls upon the Sponsor. The SCA shall be advised of all situations which involve sustaining system certification as described in paragraphs 10.2.1, 2, 3, 4, and 5.

10.2.1 Design Changes and Alterations

The SCA shall be given prior notification of all design changes and alterations within the System Certification scope or that could change the established System Certification scope. The notification shall describe the change and evaluate the effects of the change on the safe operation of the DSS in accordance with the requirements of this Manual. Accomplishment of design changes and alterations within the system certification scope without SCA concurrence shall invalidate the system certification of the DSS.

10.2.2 Repairs and Maintenance

The DSS shall be maintained so that all systems, subsystems and components within the scope of system certification operate normally before each use. The qualifications of personnel, work, and testing with regards to repairs shall be equivalent to that required in Chapter IV. Repairs and maintenance shall be performed by qualified personnel only and be recorded and initialed by a responsible person in charge. Operational logs which include post repair tests are acceptable as recordable evidence to satisfy the requirement of this Manual.

10.2.3 Periodic Inspections

Periodic inspections of systems and components within the system certification scope, if required as a condition of sustaining a system certification, shall be performed and the results reported in writing to the SCA. Each inspection record shall bear the signature of a responsible person.

10.2.4 Operating Limits

The DSS shall operate within the certified operational limits specified as part of the requirements for sustaining certification. Operation outside of the authorized operational limits may invalidate the system certification. All violations shall be reported to the SCA with cause or justifying reasons.

10.2.5 Emergency Situations

The SCA shall be advised with regard to all emergency situations which may prevent the DSS from maintaining its intended operational commitments. These may include but are not limited to, excursions below certified depth or above certified pressure, physical damage, grounding, entanglements, fires and emergency ascents or depressurizations. It is not intended that these emergency situations include failures which only temporarily interrupt the operational ability of the DSS and are corrected by routine repairs. Further, a report shall be submitted containing an evaluation of the extent of damage, proposed repair methods, and probable cause of the emergency (e.g., personnel error, operations, systems or component failures).

10.3 CONTINUANCE OF SYSTEM CERTIFICATION

"Continuance of System Certification" is the extension by the SCA of the system certification period beyond that initially granted. This is normally considered to accommodate continued use of a DSS that has had NO changes to the basic design, scope of system certification or general operating characteristics. During this "Continuance of System Certification" all requirements noted in paragraph 10.2 "Sustaining System Certification" shall be observed.

10.4 RECERTIFICATION

"Recertification" is a new certification of system adequacy for a DSS whose initial system certification has expired or been invalidated. In order to recertify, the applicant shall reestablish a scope of system certification, provide recordable evidence as noted in a renegotiated PSOB and fulfill all other requirements as were necessary for the initial system certification. Following a "Recertification" all requirements noted in paragraph 10.2 "Sustaining System Certification" shall be observed.

APPENDIX A

CATEGORIZATION OF CERTIFICATION SCOPE MATERIALS AND COMPONENTS

A.1 INTRODUCTION

This appendix contains guidelines for categorizing materials and components within the certification scope. Categorization of a material or component is dependent on its application and service experience. Because a material or component has had previous experience or use in a Naval environment does not, however, automatically place it in Category 1. The proposed application, configuration, design concepts and joining techniques must be reviewed to determine the proper category for each material or component. In other words, previous Naval experience in an application or configuration which cannot be correlated to the proposed application or configuration would, in general, disqualify the item for Category 1 and place the material or component in Category 2 which would require additional proof testing to justify its use.

A.2 CATEGORY 1

In general, Category 1 materials and components are those for which considerable operating experience is available. For hull/pressure vessel materials and external piping this would include experience in fabrication, testing and operation in a sea water environment. For piping systems, compatibility with the internal medium would also have to be known.

The following is a list of typical materials and components which are generally considered to fall into Category 1. Untested or unusual configurations or applications of these materials and components might, however, place them in Category 2.

PRESSURE HULL/VESSEL MATERIALS

*HY 80/100 - Plate - MIL-S-16216

- Forging - MIL-S-23009

- Casting - MIL-S-23008

When fabricated and welded to
requirements of NAVSHIPS
0900-006-9010

Steel Plate, High Ten- MIL-S-24094
sile, Hull and Structural

Same as above, except NAVSHIPS
0900-000-1000

Carbon Steel for Pres- MIL-S-3289A
sure Vessels for Moderate A-516,
and Lower Temperature Grade 70
Service

*These military specifications include impact property requirements for HY 80/100 material in military application. Consideration will be given to lower impact values for HY 80/100 where the applicant can show that such reduced impact requirements are adequate for the intended application of the material.

PIPING, ELECTRICAL AND LIFE SUPPORT SYSTEMS, MATERIALS AND COMPONENTS

Ni-Cu (Monel)	Cast	QQ-N-288	When fabricated and performance tested, as applicable, to appropriate specifications.
	Wrought	QQ-N-281	
70/30 Cu-Ni	Cast	MIL-C-20159	
	Wrought	MIL-C-15726	
	Tubing	MIL-T-16420	
Valve Bronze		MIL-B-16541	
Gun Metal		MIL-M-16576	
Aluminum Bronze (Min. 4% Ni)	Cast	MIL-B-23921	
	Wrought	MIL-B-24059	
Oxygen Bottles		MIL-F-22606	
Baralyme		MIL-B-36212	
Lithium Hydroxide		MIL-L-20213	
Electrical Equipment		MIL-E-16400	
Sea Water Valves		MIL-V-24287	

BOLTING MATERIAL

Ni-Cu Al Alloy	(K-monel)	QQ-N-286	Fabricated to the requirements of Screw Thread Stds for Federal Services Handbook H-28 and MS18116.
Ni-Cu		QQ-N-281	

A.3 CATEGORY 2

Category 2 materials and components have not been extensively utilized in the specific intended applications but are classed as conventional when identified by MIL-SPEC, Federal Specification or recognized American commercial standards.

A.3.1 Structural Materials

For pressure hull/vessel and other structural materials, the applicant should submit the following information in justification of the use of a Category 2 material:

a. The applicable Military, Federal, or Industrial specification involved with a detailed list of exceptions or additions.

b. Material properties for the base metal in the condition to be used and, if the material is to be welded, for the weld metal and the heat-affected-zone material.

c. Tensile properties including tensile strength, yield point, percent elongation, reduction of area, rate of loading, elastic modulus and engineering stress-strain curve (tension and compression) for the material. The material specimens tested should represent any applicable defects and variations in material properties introduced by manufacturing and fabrication processes.

d. Impact and fracture toughness properties over a range of temperatures sufficient to fully define the fracture characteristics of the material for the intended service environment (e.g., transition temperature and shelf energy values). Desirable tests would include Charpy V-notch and drop weight tests per ASTM procedures, drop weight test and/or explosion bulge tests. Where appropriate, the applicant should show that the material's fracture toughness properties in sea water are adequate for its intended use. In this regard a fracture mechanics type of test may be useful to study the effect of sea water on fracture resistance.

e. Proof of weldability and fabricability (if fabrication process includes welding). This would include results of tests such as prescribed in NAVSHIPS 0900-000-1000 "Fabrication, Welding and Inspection of Ship Hulls" for qualification of welding procedures. These test results should include tensile and impact properties of both weld metal and heat-affected base metal. A list of specific applications where the material has been successfully used in stressed applications should also be provided. Details such as quantities and thicknesses of material used, welding processes used, inspection standards used, manufacturer's name and location, location of the component in service and length of service, pre- and post-weld heat treatments, if any, and type of requirements and inspections required of the material supplier in the material purchase specifications.

f. Fatigue data, preferably data in the low cycle (below 10,000 cycles) range, which considers the effect of the environment (e.g., sea water, air, O₂, HeO₂, fresh water, mercury, etc.).

g. Basic process to be used in producing the material and the electrodes if the fabrication process included welding.

h. Data over a sufficient time period to justify the adequacy of the material with respect to general corrosion and to stress-corrosion cracking in its intended environment (e.g., sea water, air, etc.).

i. Non-destructive test requirements to be applied to base material and weld joint, as appropriate.

A.3.2 Flotation Materials

Materials used for flotation may be either liquid, solid or gaseous. As a minimum, information covering the following points should be submitted:

a. The applicable Military, Federal or Industrial specification involved with a detailed list of exceptions or deletions.

b. Data demonstrating that the material presents no hazards involving toxicity.

c. Specific gravity as a function of pressure and temperature.

d. Sustained hydrostatic collapse load, creep behavior, moisture absorption and cyclic fatigue life of solid buoyant materials in a sea water environment or in a fresh water environment when it can be demonstrated that such materials are not affected by sea water.

e. Cyclic temperature effects in an air environment must be demonstrated.

f. Information establishing that material is non-flammable under the conditions of use or, if flammable, that suitable precautions have been taken in its use.

g. Information to establish that the material can perform satisfactorily as a buoyancy material in the proposed applications. Items considered should include at least the long term storage of the material, exposure to the environmental factors of pressure, temperature, humidity, etc., and compatibility with both sea water and any containment or protective materials.

A.3.3 Hydraulic System Fluids

As a minimum, the applicant should submit the following:

a. The applicable Military, Federal or Industrial specification involved including a detailed list of exceptions or deletions.

b. Information covering resistance to deterioration, flammability and compatibility with hydraulic system components.

c. Information relating to possible toxicological hazards with the fluid.

A.3.4 Electrical Systems Materials

All electrical system materials and components should, as a minimum, meet the requirements of MIL-E-917.

A.3.5 Fairing and Miscellaneous Non-Structural Materials

As a minimum, the applicant should submit the following:

a. The applicable Military, Federal or Industrial specification involved including a detailed list of exceptions and deletions.

b. Information covering resistance to deterioration in sea water, compatibility with mating structural materials and resistance to dynamic loads such as wave slap and loads encountered in operating, handling or docking the DSS.

A.3.6 Life Support System Materials

As a minimum, the applicant should submit the following:

a. The applicable Military, Federal or Industrial specification involved including a detailed list of exceptions or deletions.

b. Data covering an extended time period justifying the adequacy of the material or component to perform in the expected temperature, pressure, humidity and atmospheric composition to which it will be subjected.

c. Data demonstrating that the material or component presents no toxic hazards.

d. Data establishing that the material or component is non-flammable under the conditions of use or, if flammable, that suitable precautions have been taken in its use.

A.4 CATEGORY 3

Category 3 materials and components are those for which definitive information and experience are not available.

Examples of Category 3 hull/vessels and other structural materials are those which are generally characterized by low ductility such as ultra high strength metals, solid glass, glass reinforced plastic and ceramic material.

For pressure hull/vessels and other structural materials, as a minimum, the applicant should submit the following information in justification of the use of a Category 3 material:

- a. Material chemistry requirements.
- b. Material mechanical properties.
- c. Basic process to be used in producing the material. Sufficient information is required to demonstrate that the procedures insure that repeatable material properties are obtainable by the process used.
- d. Data demonstrating lack of susceptibility to failure when subjected to dynamic shock resulting from explosively jettisoning external equipment, implosion of a flotation sphere or any other airbacked component or equipment contained within or transported by the DSS.
- e. Effect of flaws such as cracks or defects on material performance.
- f. Effects of temperature on material performance and resistance to crack propagation.
- g. Results of tests to destruction of samples fabricated from the materials and comparison of these results with the design basis predictions of the failure point.
- h. Fatigue data in the high strain, low cycle range (less than 10,000 cycles) in environment (e.g., sea water, air, HeO_2 , etc.).
- i. Data covering an extended time period establishing the adequacy of the material with respect to general corrosion and to stress-corrosion cracking in sea water in the presence of cracks, assuming the material is exposed to this type of environment.
- j. Fabrication characteristics including data verifying the repeatability of results.
- k. Non-destructive test requirements to be applied to the base material and joints as appropriate.
- l. Hazards involved in fabrication or use of material with respect to toxicity or flammability.

A.4.1 Viewing Window Materials

Information on viewing window materials should be submitted in accordance with the requirements for hull/vessel and other structural materials above. Particular emphasis

should be placed on the cold flow or creep characteristics of the window material under maximum test pressure and temperature extremes of a duration longer than the longest intended mission and the effects of flaws and operational stresses.

A.4.2 Flotation Materials; Hydraulic, Piping, Life Support and Electrical Systems;
Materials and Components

As a minimum the applicant should submit the information required in A.3 plus additional information as may be required by the SCA to justify the use of Category 3 material or components.

APPENDIX B

DESIGN PARAMETERS FOR DEEP SUBMERGENCE SYSTEMS

B.1 INTRODUCTION

This appendix provides guidance in the design of various individual subsystems and components of a DSS. It is not to be considered as all inclusive but rather to provide an indication of those areas of design in which experience exists and in which design parameters have been established.

B.2 DESIGN OF PRESSURE HULL/VESSEL, HARD STRUCTURE AND PIPING SYSTEMS

This section provides guidelines and requirements for design and analysis of pressure hulls/vessels, systems and other pressurized components and structures within the certification scope. They do not necessarily cover all design areas which should be evaluated by the applicant. In the design analysis, consideration should also be given to any additional conditions such as effects of shock and vibration, creep, thermal transients, material deterioration due to radiation effects, etc., which may be applicable to a specific design and/or application.

a. Fatigue

When the material of construction of the pressure hull/vessels, hard structure, piping or piping components is in Categories 1 or 2 a fatigue analysis should be submitted. This fatigue analysis may be based on specimen and/or model tests. Suitable fatigue strength reduction factors should be applied to the specimen or model test results to account for variations in properties, scatter in test results and the uncertainties involved in applying specimen and model fatigue data to fabricated full scale structures. This fatigue analysis should consider at least the following design parameters:

(1) Magnitude and nature of peak stresses. Stress concentration factors used in the calculation of peak stresses should be based on experimental data on similar structures.

(2) Material properties and method of fabrication.

(3) Notches and flaws in the material.

(4) Geometry of structure and details of penetrations and attachments.

(5) Previous fabrication history, stress history and operating history.

(6) Effect of residual stresses, thermal stresses and strain rate.

(7) Type and method of loading and environmental conditions such as corrosion/erosion. When the pressure hull/vessel hard structure piping and components are constructed of Category 3 material sufficient destructive fatigue tests of full scale prototypes, models, penetration mock-ups, etc., must be performed to experimentally determine the fatigue life of the design.

b. Fracture

The applicant should assure that the pressure hull, hard structure and all other components and materials within the certification scope have adequate resistance to fracture. Specifically, the design analysis submitted by the applicant should demonstrate that brittle fracture or low energy test failures are not possible modes of failure by considering at least the following:

- (1) Magnitude and nature of peak stresses, both applied and residual.
- (2) The minimum temperatures to which the structure may be subjected.
- (3) The size, location and number of flaws initially present in the material and which may occur as a result of cyclic operation.
- (4) Environmental conditions such as corrosion and/or erosion. Specifically, the effect of sea water on crack initiation and propagation should be evaluated.
- (5) The effect of engineering stress/strain levels and rates on notch toughness.
- (6) The effects of creep and strain cycling on notch toughness.
- (7) Localized effects due to penetrations, attachments and other hull or component restraints.
- (8) The effects of fabrication processes and heat treatments on the fracture characteristics of the material. In particular, for welded construction the properties of the weld metal, base metal and heat-affected base material should be considered.

The material properties used in the fracture analysis should be based on appropriate tests such as tensile and compressive tests, Charpy V-notch tests, drop weight tests and explosion bulge tests as discussed in Appendix A. Where appropriate for low ductility materials, fracture mechanics type tests may also be conducted. Further, the design analysis should consider possible variations in material properties and, in particular, the effect of material thickness on fracture characteristics. The structural design basis used by the applicant for the analysis of brittle fracture should be verified by destructive testing of pressure hull and component models and structures or, where possible, by reference to existing information and service experience.

For Category 3 materials which are not ductile in the usual sense, the applicant should demonstrate that, for all the conditions listed above, a sufficient margin against catastrophic brittle fracture is provided.

B.2.1 Design Strength Parameters of Externally Loaded Pressure Hulls/Hard Structure

In general, the applicant should demonstrate that the collapse pressure hull and hard structure is at least 1.5 times the design operating pressure under loading conditions (environment, loading rate and duration) representative of those expected in service, whether the collapse is by elastic or inelastic instability. The collapse pressure to which this and subsequent requirements apply is the lowest pressure at which any one of a series of nominally identical hull structures would collapse. As such, the collapse pressure (analytical and experimental) must take into consideration the effect of basic material characteristics including creep, ductility and anisotropy and must account for statistical fabrication and

geometrical variations to assure adequate reproducibility. Examples of pertinent variables include in-service material reproducibility, fabrication flaws and defects, hull openings and intersections of different shells of revolution and attendant reinforcement(s), residual fabrication stresses and deviations from the nominal geometry (flat spots, mis-match, tilt, out-of-roundness, out-of-planeness and out-of-sphericity). The following requirements should be met in order to accomplish this objective.

a. Inelastic Stability ("Yield")

For stable hull structures (i.e. stiffened or unstiffened shells which permit the level of load-induced membrane stresses to approach the material yield point at collapse) the collapse pressure must be no less than 1.5 times the design operating pressure. In determining the pressure at which collapse occurs all fabrication and design-induced restraint and geometrical variables must be considered and their effect(s) included since the strength of moderately stable hulls can be detrimentally affected by such variables (i.e., collapse can occur at actual levels of membrane stress below calculated levels of yield point intensity).

b. Elastic Stability ("Buckle")

(1) For stiffened or unstiffened hull structures fabricated from either Category 1 or 2 material and having a propensity for failure in an instability mode (i.e., collapse occurring at actual stress levels appreciably below the material yield point) the collapse pressure at which failure due to instability occurs must be no less than 1.5 times the design operating pressure. When the hull requiring verification is not proof tested at a depth of 1.5 times the maximum operating depth (c. (3) below) the applicant shall justify applicability of proven fractional buckling coefficient used in strength calculations to account for the higher scatter normally associated with structures which collapse in this mode.

(2) For Category 3 materials an appropriate ratio of collapse to operating pressure shall be justified by the applicant. This ratio shall not be smaller than values given for Category 1 and 2 materials.

c. Verification of Calculated Collapse Pressure

For Category 1 and 2 materials the calculated collapse pressure should be verified by destructive testing or use of existing destructive tests. There are three alternative methods which can be used to satisfy this method of verification.

(1) Where comparable hull geometrics and identical materials have been successfully tested to a pressure at least 1.5 times the maximum operating pressure of the structure (i.e., achieved design collapse pressure and failure mode) use of this test data can be substituted for destructive testing of the structure under review. In instances where this method of approach is applicable, and where minor differences exist between the hull structure tested and that requiring verification, the differences must be brought to the attention of the SCA.

(2) For new designs that do not fall within the parameters described in (1) above, the calculated collapse pressure may be verified by performing representative destructive model tests, either full or reduced scale. Where such testing is performed, the structural model should be sufficiently large to contain representative prototype geometries, material properties as well as fabrication restraints, tolerances and residual stress.

(3) For as-built hull designs which by refined calculation have a collapse pressure in excess of 1.5 (e.g., approximately 1.75 or greater) times design operating pressure (b. (1) above), full scale pressure testing of the hull structure requiring verification to 1.5 times the maximum operating pressure will be acceptable as verification of the calculations.

For Category 3 materials the calculated collapse pressure and the reproducibility this collapse pressure should be verified by destructive model tests and/or appropriate destructive proof tests of a duplicate prototype hull, as appropriate. An acceptable destructive model test is one performed on a model whose scale is such that the mechanical properties of the material are either identical or differ by a known factor of magnitude from those in the full scale hull built from the same material and incorporates all structural details of the full scale hull.

For any material the test method should duplicate the loading conditions expected in service and, where applicable, should be such that the mode of failure is identifiable. Where appropriate, use may be made of prior experimental results obtained on similar fabricated structures.

d. Verification of Design Strength (Proof Test)

A proof test shall be performed on all pressure vessels, hard structure, and penetration fittings that are subject to external pressure. Hard spots (i.e., areas of discontinuity) should be instrumented. The test fluid should be representative of the expected environment and at a temperature equal to or colder than the coldest expected operating temperature. The test time should be sufficient to demonstrate that the combined stress/temperature/time loadings are not critical. For Category 1 and 2 materials, the proof test pressure (for submersible hulls - between 1.10 and 1.25 times the design operating pressure) should not produce permanent deformation in the component, or the operation of the component. For Category 3 materials a technically justifiable hydro proof test is in order. For example, a conventional proof test would not be appropriate for materials whose performance would not be reproducible in such tests. Guide lines for testing pressure vessels and hard structure which are of a size and shape not suitable for pressure chamber testing may be provided on a case basis.

e. Stress Analysis

The applicant should perform a complete stress analysis of the hull and hard structure and demonstrate that its fatigue life is adequate for the intended certification period. It is also expected that static stress levels will be limited to values such as those given below by the collapse strength requirements discussed in paragraph B.2.1. The following stress levels are given as guidelines for Category 1 and 2 materials and, with the exception of peak stresses, the applicant is not required to demonstrate compliance with these specific stress values.

(1) The average shell membrane stress at design operating pressure should be limited to approximately $2/3$ of the minimum specified yield strength of the material.

(2) The highest valued combination of average shell membrane stress and bending stress (excluding effects of local stress concentrations, e.g., small fillet radii) at design operating pressure should be limited to approximately $3/4$ of the minimum specified yield strength of the material. The effect of all external loads and transitions and stiffener-to-shell connections should be considered.

(3) The maximum peak stress at any point in the hull, including effects of local stress concentrations, shall be limited by fatigue considerations as discussed in paragraph B.3 below. In addition, to insure an adequate fatigue resistance for some designs using Category 1 and 2 materials, it may be necessary to reduce the level of combined membrane and bending stress to a level below that given in (2) above.

(4) The applicant should calculate stresses in the pressure hull by means of any recognized stress formulae or proven computer programs. A computer program should be "proven" by demonstrating agreement with experimental test results or manually obtained predictions. The validity of the stress analysis methods used should be demonstrated by experimental results and a prior experience with similar structures.

(5) For hulls constructed of Category 3 materials the foregoing design requirements and guidelines may not be appropriate or adequate. Therefore, the applicant is not limited to use the above design basis. The design basis used, however, must be comprehensive and provide at least the same degree of conservatism as the design basis for Category 1 and 2 materials.

B.2.2 Design Strength Parameters of Internally Loaded Pressure Vessels 'Hard Structure

In general, the applicant should demonstrate the structural integrity of the pressure vessel and hard structure under loading conditions (environment, loading rate and duration) representative of those expected in service. As such, the design operating pressure (analytical and experimental) must take into consideration the effect of temperature, cycle loading, creep, ductility and anisotropy. Examples of pertinent variables include pressure, temperature, cycle loading, in-service material reproducibility, fabrication flaws and defects, vessel openings and intersections of different shells of revolution and attendant reinforcement(s), residual fabrication stresses and deviations from the nominal geometry (flat spots mis-match, tilt, out-of-roundness, out-of-planeness and out-of sphericity). The following requirements should be met in order to accomplish this objective.

a. Inelastic Stability ("Yield")

For stable vessel structures (i.e., stiffened or unstiffened shells which permit the level of load-induced membrane stresses to approach the material yield point), the ratio of the yield pressure to the design operating pressure should be justified. In determining the pressure at which yield occurs, all fabrication and design-induced restraint and geometrical variables should be considered and their effect(s) included since the strength of moderately stable vessels can be detrimentally affected by such variables (i.e., yield can occur at actual levels of membrane stress below calculated levels of yield point intensity).

b. Verification of Calculated Design Operating Pressure (Proof Test)

For Category 1 and 2 materials, the calculated design operating pressure should be verified by destructive model testing or use of existing non-destructive tests. There are three alternative methods which can be used to satisfy this method of verification.

(1) Where comparable vessel geometrics and identical materials have been successfully tested to a pressure greater than the maximum operating pressure of the structure, use of this test method can be substituted for destructive model testing of the structure under review.

(2) For new designs that do not fall within the parameters described in (1) above, the calculated maximum allowable pressure may be verified by performing representative destructive model tests, either full or reduced scale. Where such testing is performed, the structural model should be sufficiently large to contain representative prototype geometrics, material properties as well as fabrication restraints, tolerances and residual stress.

(3) For as-built vessel designs, which by refined calculations have a yield pressure in excess of the design operating pressure, full scale pressure testing of the vessel structure to 1.5 times the maximum operating pressure may be acceptable as verification of the calculations.

It is recognized that many existing pressure vessels were built and tested to codes less stringent than current pressure vessel codes. In these cases the applicant should carefully weigh past and present acceptance criteria when determining the parameters for which he is seeking system certification. (Case in point = A recompression chamber that was designed and built to ASME - Sect VIII - Div. 1, but is lacking back-up recordable evidence to assure the pressure vessel met the original design parameters, may be considered materially adequate to perform functions to parameters less than original specifications with a minimum of additional testing.)

For Category 3 materials, the calculated yield pressure should be verified by destructive model test. A destructive model test is one performed on a model whose scale is such that the mechanical properties of the material are either identical or differ by a known factor of magnitude from those in the full scale vessel, built from the same material, and which incorporates all structural details of the full scale vessel.

A conventional non-destructive proof test may not be appropriate for materials whose performance would not be reproducible in such tests.

For any material, the test method should duplicate the loading conditions expected in service and, where applicable, should be such that the mode of failure is identifiable. Where appropriate, use may be made of prior experimental results obtained on similar fabricated structures.

c. Stress Analysis

The applicant should perform a complete stress analysis of the vessel and hard structure and demonstrate that its fatigue life is adequate for the intended certification period. It is expected that static stress levels will be limited to values below the yield strength requirements discussed herein. The following stress levels are given as guidelines for Category 1 and 2 materials and, with the exception of peak stresses, the applicant should demonstrate compliance with these specific stress values.

(1) The average shell membrane stress at design operating pressure should be limited to approximately $2/3$ of the minimum specified yield strength of the material.

(2) The highest valued combination of average shell membrane stress and bending stress (excluding effects of local stress concentrations, e.g., small fillet radii) at design operating pressure should be limited to minimum specified yield strength of the material. The effect of all external loads and transitions and stiffener-to-shell connections should be considered.

(3) The maximum peak stress at any point in the hull, including effects of local stress concentrations, should be limited by fatigue considerations. In addition, to insure an adequate fatigue resistance for some designs using Category 1 and 2 materials, it may be necessary to reduce the level of combined membrane and bending stress to a level below that given in (2) above.

(4) The applicant should calculate stresses in the pressure vessel by means of any recognized stress formulae or proven computer programs. A computer program should be proven by demonstrating agreement with experimental test results or manually obtained predictions. The validity of the stress analysis methods used should be demonstrated by experimental results or prior experience with similar structures.

(5) For vessels constructed of Category 3 materials, the foregoing design requirements and guidelines may not be appropriate or adequate. Therefore, the applicant is not limited to using the above design basis. The design basis that is used, however, should be as comprehensive, and provide at least the same degree of conservatism, as the design basis for Category 1 and 2 materials.

B.2.3 Design of Piping Systems

a. Piping systems should be designed to withstand, without failure, all anticipated service loadings such as:

- (1) Weight of pipe, fittings, valves and contained fluid.
- (2) Internal or external pressure, static and cyclic.
- (3) Deflections and rotations of structure and equipment at points of pipe attachment.
- (4) Restraint of hangers and support.
- (5) Thermal expansion and transients.
- (6) Shock, vibration and water hammer.

b. Piping designed to carry over 500 psi and piping which, if ruptured would depressurize the DSS should be protected against damage by suitable routing or shielding. Systems adjacent to lines designed to carry over 500 psi should be protected by suitable shielding or routing at a safe distance. Lines should be routed so they cannot be used as handholds. Lines should be made of one piece, whenever possible, within assembly, disassembly, and maintenance restrictions. Connectors should be designed and arranged so that it is physically impossible to connect a system of one pressure level to one of another pressure level. If gas reservoirs such as cylinders are included in a system, a valve should be provided to stop gas flow from the reservoir. The valve must be able to withstand full reservoir pressure, plus a sufficient safety factor.

c. High-pressure lines and fittings made of special material should be identified to prevent replacement with a part made of unsuitable material.

d. Piping and tubing should be supported as close to bends as possible and should not, themselves, be used to support components such as valves, relief valves, check valves, and filters. One line should not be used to support another. Clamp blocks may be used to support two or more adjacent lines with the clamp blocks attached to suitable structural members.

e. The number of pipe joints should be kept to a minimum. The applicant must justify the selection of the type of joint used. The justification is to include such information as previous similar service experience, nondestructive tests and developmental testing.

f. All pipe joints should be accessible for inspection. Antiseize tape should be used on all male pipe-thread fittings.

g. Piping should be designed to have sufficient flexibility to prevent failures such as:

- (1) Failure of the system from overstressing materials or anchors.
- (2) Leakage of joints.
- (3) Distortion of connected equipment and structures which exceeds the limits specified for them or renders them inoperable.
- (4) Stress corrosion failure.

h. The structural adequacy of the piping system should be demonstrated by the applicant for all anticipated service loadings. This may be accomplished by meeting the design requirements for internally pressurized components, as outlined in paragraph B.2.4 below, or by use of established American Industrial standards where the applicant can show that a substantial body of service experience exists in similar applications. In addition, the applicant should, where feasible, show that the fatigue life of the piping system is adequate by performing a fatigue analysis as outlined herein.

i. It is desirable that piping flexibility calculations be performed by the applicant as a further measure of assurance prior to material certification. Detailed sketches of piping under examination may be submitted with calculations and form a part of the calculation report. Calculations should show maximum stresses and their locations in each section of piping under examination. Calculations should be submitted in a detailed form that will permit their review without difficulty and should include a statement delineating:

- (1) Theoretical basis of calculations
- (2) Method of performing calculations
- (3) Simplifying assumptions
- (4) Sign conventions
- (5) Assumed material and dimensional data
- (6) Other pertinent information such as hull deflections

j. The piping flexibility analysis may consider the added flexibility of piping components. Flexibility factors should be in accordance with the USAS B 31.1 Code for pressure piping. Piping components for which there are no flexibility factors listed in USAS B 31.1 should be considered rigid unless the applicant can justify the use of added flexibility.

k. The applicants' piping flexibility analysis should include calculations of the bending moments, twisting moments, and reaction forces imposed on each component in the piping system.

l. All lines should be identified and labeled to indicate function, content, maximum pressure, and direction of flow preferably according to MIL-STD-1247, "Markings, Functions, and Hazard Designations of Hose, Pipe, and Tube Lines for Aircraft, Missile and Space Systems." However, it is not intended that this manual provide specific construction requirements. There are some situations where such standardization is considered important for continuity and personnel training. The color coding of MIL-STD-101 "Color Code for Pipelines and for Compressed Gas Cylinders" is recommended for Deep Submergence Systems design requirements except as noted below:

<u>Gas System</u>	<u>Designation</u>	<u>Color Paint</u>
Helium	He	Buff
Oxygen	O	Green
Helium-Oxygen mix	He-O	Buff and Green
Nitrogen	N	Light Gray
Exhaust	E	Silver

<u>Gas system</u>	<u>Designation</u>	<u>Color Paint</u>
Air (low pressure or high pressure)	ALP, AHP	Black
Chilled Water	CW	Blue and White
Hot Water	HW	Red and White
Potable Water	FW	Blue

The use of military standards in DSS applications is encouraged in preference to other standards that could be used in a DSS. A condition could occur wherein the standard invoked for a support ship and for a supported DSS could be conflicting. For example, a color code standard specifying orange for use in Helium-oxygen applications is not compatible with a color code standard specifying orange for use in hydraulic oil applications. The sponsor must insure the personal safety compatibility of existing standards at the intended use site.

B.2.4 Design of Piping Components

It is desirable that the applicant perform a stress analysis of each piping system component design. This analysis should consider all anticipated loading conditions including the loads calculated in the piping flexibility analysis discussed above. Applicable requirements are given below:

- a. The structural design requirements used for externally pressurized components should not be less than the requirements for the pressure hull and hard structure.
- b. For internally pressurized components of Category 1 and 2 materials the following structural design basis should be used:

- (1) The allowable operating stress, S_m , should be taken as the lesser of 2/3 of the minimum specified yield strength or 1/3 of the minimum specified tensile strength for ferrous materials and the lesser of 2/3 of the minimum yield strength or 1/4 of the minimum specified tensile strength for non-ferrous materials.

- (2) General membrane stress should not exceed S_m .

- (3) Local membrane stress must not exceed $1.5 S_m$.

- (4) The highest valued combination of membrane stress and primary bending stress must not exceed $1.5 S_m$.

- (5) The highest valued combination of primary and secondary stresses must not exceed $3 S_m$.

- (6) Peak stresses, including effects of local stress concentrations, must be limited by fatigue considerations, as discussed in paragraph B.3 below.

- (7) The various categories of stress which should be considered in the applicant's stress analyses are defined below:

- (a) Primary Stress - A primary stress is one which is required to produce a state of equilibrium with the applied loads. The basic characteristics of a primary stress is that it is not self-limiting. Primary stresses are further classified as follows:

- General Membrane Stress - Average value of primary stress across a solid section, excluding discontinuities and concentrations. An example of a general membrane stress is the average stress across the thickness of a pressurized cylindrical shell.

- Local Membrane Stress - Average primary stress across any thickness at a particular location on the pressurized component. This includes the effect of discontinuities but not stress concentrations. Also, it is limited in extent to a relatively small area of the component. An example of a local membrane stress is the membrane stress in a shell produced by external load or moment at a permanent support or nozzle connection.
- Bending Stress - Primary stress at a particular location on the pressure hull which is proportional to the applied or induced moments and is proportional to distance from the centroid of a solid section. The effects of discontinuities and concentrations are excluded. An example of a primary bending stress is the stress in the central portion of a flat head due to pressure.

- (b) Secondary Stress - A secondary stress is one which is developed by the constraint of adjacent parts of structure and which is not required to produce equilibrium with the applied loads. Secondary stresses are self relieving in nature and are necessary to satisfy continuity of the structure. Examples of secondary stress are the discontinuity bending stresses at a head-to-shell or shell-to-flange junction.
- (c) Peak Stress - The maximum combined stress at any point in the structure. The peak stress at a given point will be the maximum combined primary plus secondary stress suitably increased to account for local stress concentrations. The basic characteristic of a peak stress is that it does not cause any noticeable distortion and is of concern primarily as a possible source of a fatigue crack or brittle fracture. An example of a peak stress is the maximum stress at a notch or other small discontinuity in a structure.

c. For components whose geometry is not amenable to analytical evaluation, and when considered appropriate by the applicant, the structural adequacy of piping system components may be verified experimentally. In this case, a comprehensive experimental stress analysis and/or a burst test such as specified in the ASME Boiler and Pressure Vessel Code, Section VIII, may be performed in lieu of an analytical stress analysis.

d. For components constructed of Category 3 materials, the applicant is not required to use the structural design basis outlined above. However, as in the case of pressure hulls constructed of Category 3 materials, the applicant must show that the design basis used is at least as inclusive and conservative as the basis discussed above. Further, the structural adequacy of components constructed of Category 3 materials must be verified by tests of full-scale prototype components.

e. All piping components should be designed or selected for flow that is adequate for the mission conditions expected for the DSS. These conditions should be specified in justifying the design or selection.

f. All manually-operated piping components should be readily accessible and easily operated under mission conditions.

g. In order to minimize interference with gas flow, flow-control piping components must be capable of controlling gas flow within the required design limits and should be designed with as few moving parts as possible.

h. If the flow-control component is adjustable, it should provide a smooth, even flow change as it is operated. If orifices are used to control flow, the orifice size should be easily identifiable. Provision should be made for clearing or by-passing clogged orifices during use.

i. Exhaust components may either be adjustable or be nonadjustable.

j. Exhaust components used in dry suit diving equipment should be provided with a manual override device.

k. A check or non-return piping component is to be provided in the gas system when one-way flow is required for the safety of the DSS personnel or for normal operation of the equipment. A non-return valve should always be provided at the inlet of a hardhat, dry suit system.

l. Maintenance and inspection procedures for non-return components should be clearly stated to insure proper operation at low pressure differentials.

m. Mechanical friction or bite-type connections should not be used on piping components subject to internal or external operating pressure, unless the applicant can furnish sufficient information to demonstrate that the integrity of the connection will be preserved under service conditions. This must include consideration of reuse of the fittings and possible work-hardening of the associated tubing.

B.2.5 Design of Penetration Fittings

Design calculations and analyses should be conducted to establish the adequacy of all piping, mechanical and electrical penetration fittings of the pressure hull and hard structure. The fittings must be adequate for the design life and the intended service conditions. Possible modes of failure, including leakage should be considered. When internal pressure is a loading, the requirements of paragraph B.2.2 apply. The requirements of paragraph B.2.1 should apply to those portions of the fittings subjected to external submergence pressure. Sufficient testing must be performed to confirm the structural adequacy and leak tightness of each of these fittings.

a. Penetration

All readily accessible vents, drains, exits or exhaust, from the pressurized volume, which would not be in use during the period that the DSS is pressurized, should be provided with covers or stoppers so that the number of potential, accidental exhaust paths may be kept to a minimum. The applicant should show that all penetrations are adequately sealed.

The body of electrical pressure vessel penetrators and connectors that may be exposed to sea water or spray should be corrosion resistant. Electrical penetrations of the pressure-containing structure must be gas-tight even in the event of damage to the connecting cables.

Electrical cable pressure vessel penetrators should provide a water barrier at the hull to prevent flooding of the DSS in the event of failure of the external cable. Stuffing tube type penetrations of the pressure capsule or other hard structure are not generally acceptable. Pin type connections for cable entrances into compensated enclosures are preferred, however, terminal tube entrances are acceptable provided evidence of compatibility of the cable jacket and insulation with the compensating medium is provided.

Provisions shall be made to protect the pressure vessel from corrosion in the basketed areas of the penetrators.

Placement of pressure vessel penetrations should be such that minimum flooding and/or loss of atmosphere will occur in event of a broken line. Emergency shut-offs also should be provided for such a contingency.

b. Viewports

The applicant must show that the viewport design is adequate for the purpose. Each port's field of view within the DSS should be shown on drawings. The materials used must have adequate fatigue strength for the stresses to be imposed upon them during their specified service life. Resistance to stresses applied continuously over a long period, as well as cyclic stresses, must be properly considered. Full specification must be made of the materials used; composition; thermal, chemical, or physical treatment required; dimensions and tolerances; and renewal or replacement criteria. Where necessary, ports must be protected against accidental blows or other mechanical abuse.

c. Hatches and Closures

The applicant must show that all closures, including hatches for personnel or materials, port covers (deadlights) and caps or plugs for openings of other types have adequate strength for their application. The method of sealing must be specified in sufficient detail to permit evaluation. Ease and rapidity with which a closure can be closed or opened from inside or outside the DSS, and whether tools are required, are design considerations which vary according to the application. In the case of any closure for which these factors are important, attention should be drawn to them and the appropriateness of the design explained.

Hatch hinging, closing, locking and sealing elements must be made resistant to or be protected from abuse due either to rough handling or to credible accidents such as blows from a personnel transfer capsule which is being attached to the DSS hurriedly in rough weather.

Design of the hatches must permit safe operation under specified ship motions.

d. Seals

Sealing materials and techniques must be shown to be adequate for the range of pressures, gas mixtures, temperatures, vibrations and atmospheric environments specified for the chamber. Seals should be proof against failure due to the effects of a non-lethal, extinguishable fire inside or outside the chamber, attack by the fire extinguishing agent used in the chamber and thermal shock caused by its application. The effect of pressure cycling, stress concentrations, differential thermal expansion, differences in modulus of elasticity and aging should be considered. Tolerances must be considered to prevent seal failure, viz., nibbling and extrusion.

B.2.6 Piping System Design Verification

a. Piping systems, either gaseous or liquid, located inside the DSS should successfully pass a hydrostatic or pneumatic strength test at a pressure equal to at least 1.5 times the design operating pressure to assure system strength. The pressure should be maintained for a period of time sufficient to permit a thorough inspection of all points of

suspected stress raisers (e.g., rapid changes in section or sharp discontinuities) and brazed, welded and or mechanical joints. There should be no evidence of distortion or leakage except that leakage which may result from loose or faulty seals in mechanical joints. Following this test, the pressure should be reduced to 1.1 times the design pressure and the tightness of all mechanical joints checked. If the tests indicate that a leak exists, it should be located and eliminated unless a special leakage acceptance criterion can be justified by the system designed which will not effect the safety of the DSS's occupants. Procedures, test duration, leakage criteria, etc. should be submitted for review by the SCA.

b. Subsequent tests for those same systems, assuming that they do not undergo a configuration change and that component replacements are made "in kind," should be tested to 1.1 times the design operating pressure for tightness. Should a change in materials, components or configuration be required, that portion which has been changed should be tested to 1.5 times operating pressure for strength and then 1.1 times operating pressure for tightness. The remaining portions should only require pneumatic or hydrostatic tests to 1.1 times the design operating pressure for tightness.

c. Piping systems or portions thereof, located external to the DSS, should be subjected to tests for strength and tightness at least twice.

(1) With an external pressure equal to the DSS design test depth and an internal pressure at one atmosphere, there should be no indication of leakage from outside the system to the internal portion of the system. Pressure should be maintained for a period of time sufficient to permit a thorough inspection of all joints. There should be no evidence of distortion or leakage.

(2) With the external pressure at one atmosphere and the internal pressure equal to at least 1.5 times the system design operating pressure, strength and tightness should be tested in accordance with the criteria in paragraph B. 2. 4 above. Burst discs or pressure-relief valves that are required by the various codes to prevent rupture, if installed on man-rated DSS, must not be permitted to present a hazard to the operator, diver or occupant by causing rapid decompression should they be actuated by a malfunction or extreme in pressure.

B.3 FABRICATION DESIGN CRITERIA

The applicant should include a review of the fabrication aspects of the design and/or test results to justify that joints, connections, forming, shaping, machining, etc., are sufficient to provide the quality and strength required by the calculations. Detailed requirements are:

a. Piping System Joints

The applicant should justify the selection of the type of joint design and method of joining used. The number of piping joints should be kept to a minimum. The justification should include such information as previous similar service experience, non-destructive test requirements specified to insure that constructed joints meet design requirements and developmental testing to qualify the method of fabrication.

Lines which are required to be disconnected during normal operation of the DSS or during normal overhaul or inspections, should be provided with suitable closure devices for each exposed connection to prevent ingress of foreign materials when the system integrity is broken. Caps which introduce moisture and tapes that leave adhesive deposits should not be used for this purpose. Closure devices should be stored, when not in use, in such a manner as not to become contaminated.

Flexible hose is a poor substitute for rigid tubing and is to be considered only where system flexing or vibration dictates its use and rigid tubing is neither acceptable nor practical. When flexible hose is to be subjected to considerable vibration or flexing, sufficient slack should be provided to avoid mechanical loading. Sharp bends or twisting should be avoided. A pressure safety factor of four should be the minimum used with flexible hose.

All flexible hose connectors should be designed so they cannot be connected into the wrong system. This can be done by size selection, key fit or other means. Coding or identification alone is not generally considered sufficient.

Where hand-operated water hoses are used they should be electrically conductive and grounded to reduce the risk of electric shock to the user in case they should be used inadvertently against live electrical equipment.

b. Mechanical Friction or Bite-Type Connections

Mechanical friction or bite-type connections should not be used in applications subject to internal or external submergence pressure unless the applicant can furnish sufficient information to justify the integrity of the connection under the service conditions. This should include consideration of reuse of the fittings and possible work-hardening of the associated tubing.

c. Threaded Fasteners

The design of all threaded fasteners including bolts, studs and nuts should meet the requirements of the National Bureau of Standards Handbook H-28. Studs and nuts should be of sufficient length so that nuts, when tightened, expose at least 1 1/2 excess threads.

d. Locking Devices for Mechanical Fasteners

The need for locking devices for mechanical fasteners should be evaluated by the applicant. A locking device that meets the following functional requirements is generally considered satisfactory:

- (1) Provides a positive locking action.
- (2) Is relatively simple to install.
- (3) The design lends itself to inspection that will insure proper installation without disturbing the locking feature.
- (4) Is not normally reused.

If the designer selects locking devices that do not meet the above criteria, such as blind self-locking hardware or reusable insert type fasteners, he should furnish sufficient information to justify the safety and integrity of the connection under the service conditions. The justification should include recommended inspection procedures and acceptance standards.

e. Finishes

Finishes applied to pressure-containing elements should not be of a type likely to permit the development of hidden pitting. Metal applied as a surface finish, coating or

cladding, should be lower on the electrochemical scale than the metal to which it is applied. The use of dissimilar metals in contact, where dissimilar metals are defined by Military Specification 33586, "Metals, Definition of Dissimilar," should in each case be justified by the applicant as not presenting an unacceptable corrosion situation.

f. Fracture Toughness

All plates, parts, and components should demonstrate adequate strength and toughness at the design operating temperature. Toughness characteristics of ferrous materials should be referenced to the Nil Ductility Transition Temperature (NTD).

B.4 GENERAL REQUIREMENTS FOR DESIGN OF LIFE SUPPORT SYSTEMS

The overall life support system should include those items required to provide a safe environment for all personnel utilizing the DSS. It may include a means for providing a reserve of breathing gas which is to be used by diver for a safe return to the surface or to an underwater station. The applicant should provide a detailed design description of the life support system. The design description should provide justification as to the life support system capability to provide required services consistent with design operational requirements of the DSS.

The justification should include consideration of the duration of DSS operation (length of mission), dive scenario, number of personnel embarked on the DSS, physical activity of personnel, volume of personnel enclosure, ambient environment, etc.

The amount of redundancy required in a life support system should be based on the duration of operation of the DSS. As an example, a DSS that is to operate without a support ship should have sufficient duplication of life support services so that, if a failure of a life support service occurred, the DSS could return the personnel to a safe haven.

The application should furnish data on actual operating characteristics obtained by test and on the reliability of the life support system. These data may be based on either previous history of use or on the results of life test data.

The design of life support systems should consider the following services necessary for atmospheric control and monitoring:

- a. Breathing Mixture Supply System
- b. Carbon Dioxide Removal System
- c. Hydrogen, Carbon Monoxide and Toxin Removal Systems
- d. Air Purification and Filtering System
- e. Atmospheric Monitoring System
- f. Emergency Breathing Supply System

B.4.1 Atmospheric Control

a. The Breathing Supply System capacity, as a minimum, should be sized on the basis of providing sufficient oxygen to meet the human oxygen and air consumption rates given in Appendix E.

b. The Carbon Dioxide Removal System should be sized in accordance with CO₂ generation rate given in Appendix E.

c. The applicant should identify the gaseous and particulate contaminants expected in the DSS. The applicant should substantiate that the Toxin Removal System and the Air Purification and Filtering System are capable of limiting the representative air contaminants to the levels given in Appendix E. This should be verified by actual analysis during the DSS acceptance tests. A recommended test procedure is given in Appendix F.

The method specified for cleaning breathing gas systems must be capable of removing particulate matter as well as grease, oil, and other contaminants. It is important that no toxic, outgassing or combustible residues remain after the cleaning operation, and that the cleaning operations not cause degradation of the breathing-gas system components.

B.4.2 Emergency Breathing Supply System

An Emergency Breathing Supply System should be provided to be used only in an emergency and not in normal operations. The system must be separate and distinct from other atmosphere control systems. The system must be capable of providing proper breathing mixtures in the event of failure of the primary system or fire. The system should provide for voice communications and provide acceptable breathing (exhalation) resistance and comfort. All materials used in this system should be fire and heat resistant and their use be justifiable. The capacity of the system should be sufficient to allow time either for normal ascent from operating pressure/depth plus at least a 50% margin, for sufficient time for a diver to reach another breathing-gas source, or for such other time that will permit corrective measures to be taken. The capacity of the emergency supply must be stated in the detailed specifications of the DSS.

B.4.3 Atmospheric Monitoring Instrumentation

Atmospheric Monitoring Instrumentation should be provided for the DSS to warn operators, divers and passengers of unsafe atmospheric conditions. Suitable redundancy of instrumentation should be provided and should be particularly designed to operate in the event of normal power failure.

Oxygen sensors should be equipped with high- and low-limit alarms and carbon-dioxide sensors should be provided with high-level alarms. Alarms preferably should be both visual and audible.

Automatic transfer to reserve breathing-gas supply, if provided, should actuate a warning signal, preferably both audible and visual. Provision may be made for turning off the warning device after it has been activated. Consideration should be given to providing automatic reactivation of the warning after a specified time.

Checking the status of the emergency supply must be required as a part of the pre-dive procedure.

The applicant should show that the equipment is reliable, has sufficient accuracy and will operate satisfactorily within the range of design parameters and environment.

B.4.4 Miscellaneous

a. Bottled Breathing Gas, Oxygen

Breathing gas containers may be used to provide compressed air or synthetic breathing atmospheres to the DSS. They may comprise the normal and/or emergency gas supply. Special requirements, which may be necessary because of the composition of breathing gases, must be established independently for each situation and are not specifically covered in this manual.

When bottled breathing gas oxygen or air is installed, the applicant should provide the following:

(1) Assurance that the normal supply container(s) will provide sufficient gas for the longest mission expected for the DSS.

(2) Assurance that the emergency gas-supply container(s) will provide sufficient gas for the possible emergency conditions as described by the applicant.

(3) Assurance that each pressure reducing device is designed to maintain the outlet pressure within required limits despite varying inlet pressure of flow. When set to the required outlet pressure, regulation should not be markedly affected by position, motion, activity or environmental temperature. Regulation should be shown to be satisfactory within the design operating depths.

(4) An isolation valve downstream of the regulating valve, capable of withstanding full bottle storage pressure should the regulating valve fail. The isolation valve must be capable of manually regulating pressure. A bypass valve around the regulating valve should also be included for use in the event that the regulating valve fails shut. The regulating valve should be designed to fail shut.

(5) High pressure oxygen piping of a non-ferrous material preferably of nickel-copper (MIL-T-1368) seamless, annealed tubing. High pressure portions of the oxygen system should be welded wherever possible for maximum integrity of this vital and potentially dangerous system.

(6) Suitable valve protection to prevent inadvertent depressurization of the system. For example, isolation valves should be provided for gauges, regulating valves or double valve protection of fill lines for air flasks that are permanently installed and recharged in place, double valve protection should be provided on fill lines to prevent inadvertent depressurization of the flasks.

(7) Air quality meeting the requirements as noted in Appendix E.

(8) Oxygen quality meeting MIL-O-27210 or equivalent and should be verified as to purity by the supplier.

(9) Breathing gas systems capable of being cleaned in accordance with Appendix G.

(10) Containers secured to prevent their accidental detachment and supported or restrained so that they do not impose a load on other components that are not specifically designed as supports.

(11) Assurance that the instantaneous release of the stored gas in the largest single container, which cannot be isolated leading into the DSS, will not result in an increase pressure or concentration that will then result in an immediate and severe danger to the DSS personnel.

(12) Assurance that any breathing gas pressure control subassembly provided in the form of a variable-volume gas reservoir is:

- (a) Puncture and tear resistant
- (b) Mold and fungus resistant
- (c) Configured to permit accessibility to other components
- (d) Easily removable for cleaning and airing
- (e) Resistant to collapse during normal use

b. Carbon-Dioxide Absorbers

(1) The carbon-dioxide (CO₂) level must be controlled in the breathing gas that is recirculated in the DSS or the diver in semi-closed and closed circuit breathing equipment. This control generally is effected by passing the expired gas through a canister that contains a CO₂ absorbent material. The CO₂ absorbers must maintain the CO₂ content of breathing gas below a specified maximum value for the duration of the longest mission expected for the DSS plus a specified safety factor.

(2) All hydroxide-type absorbents are caustic. Therefore, the applicant must insure that particles of the absorbent are not carried to the DSS personnel in the flow of breathing gas.

(3) The design may consider means to remove or control moisture produced from the CO₂-absorbent reaction. This moisture may fog the DSS viewports or the diver's faceplate, accumulate in breathing-gas passages, increase resistance to gas flow through the absorbent, and decrease the effectiveness of the absorbent.

(4) CO₂ canister materials must be highly resistant to caustic attack and sea water corrosion.

(5) CO₂ canisters should be easily checked for absorbent content and condition, and should be easy to refill or replace.

(6) The applicant should consider the following features that are greatly dependent upon canister geometry:

- (a) Minimum flow resistance
- (b) Maximum utilization of absorbent
- (c) Maintenance of neutral buoyancy in use as applicable
- (d) Elimination of gas-flow channeling that severely restricts mission duration by reducing absorbent utilization.

c. Umbilicals

(1) Umbilicals include hoses and cables that tether a DSS or a diver to a base, that supply fluids, and that provide electrical connections. They should be resistant to abrasion, impact damage, cracking and deterioration, but also should be sufficiently flexible to permit free movement. Flotation characteristics of the materials may be utilized to increase maneuverability.

(2) Umbilicals should possess adequate tensile strength for their design use, adequate flexural strength to withstand coiling for storage and adequate burst strength (including an adequate safety factor) to withstand internal service pressure.

(3) Hoses, cables, and connectors should be provided with strain-relief devices. These devices should be designed to prevent damage to the hoses, cables and connectors as well as to prevent accidental disconnection of the hoses and cables if they are pulled or used as handholds.

d. Breathing Gas Hose

(1) Flexible hose is generally used to carry the breathing gas from component to component of DSS. Rupture or collapse of any section of hose can jeopardize the life of the DSS personnel. Adequate strength and compatibility with environment and breathing-gas mixtures are, therefore, the most important requirements. The applicant should demonstrate, by calculation and test, that these requirements have been met. The applicant shall justify the pressure safety factor used with flexible hose.

(2) When flexible hose is to be subjected to considerable vibration or flexing, sufficient slack should be provided to avoid mechanical loading. Sharp bends and twists should be avoided.

(3) All flexible-hose connectors should be designed so they cannot be connected into the wrong system and so that inlet and outlet gas lines cannot be interchanged.

(4) Devices used for alignment or prevention of incorrect connection should be sturdy enough to resist twisting out of shape or position.

(5) Quick-disconnect fittings and connectors shall be readily accessible and quickly disconnected in an emergency. However, provision should be made to prevent accidental disconnect.

Fittings should have the following characteristics:

- (a) Compatibility with other materials
- (b) Corrosion resistance
- (c) Ease of operation
- (d) Tight sealing
- (e) Positive locking

c. Clothing for Divers

(1) Wet Suits

- (a) The applicant should insure that materials used in suits are not hazardous to personnel during use or after extended periods of storage.
- (b) Wet suits should have sufficient thickness to maintain an adequate thermal barrier at the rated operating depth, but should have minimum drag in use. Wet suit materials should be resistant to tearing or abrading.
- (c) The applicant should insure that heated suits are adequately durable to prevent tearing, abrasion or damage to heat conductors with the possible consequences of electric shock, hot spots or loss of thermal protection. Suits should withstand repeated flexing without material degradation or loss of intended function.
- (d) Electrically heated suits should have fail-safe devices and warning indicators to preclude electric shock or burns to personnel. The suits should comply with the appropriate safety considerations for electrical equipment.

(2) Dry Suits

- (a) The suit used for dry suit diving should keep the diver dry by resisting water incursion through the dress fabric, seams or openings.
- (b) Dry suit fabrics should be resistant to tearing, abrading, or permanent deformation. Chafing patches should be installed in the areas of greatest wear and provisions should be made to permit patching as required.

(3) Gloves

Gloves should protect a diver's hands from injury and/or cold. They should be designed to interfere as little as possible with the operation of emergency equipment and quick-disconnect fittings.

(4) Weights

- (a) Weighted shoes, if required, should provide sufficient stability to prevent capsizing of the diver.
- (b) In designing weights and/or quick-release devices for weights, the applicant should consider buoyancy requirements of the diver in case of either deliberate or accidental release of weights.

(5) Headgear

Headgear includes, but is not limited to, masks that cover only the eyes and nose, face masks with oral-nasal inserts, rubber caps and mouthpieces, helmets with face seal and oral-nasal inserts, diving helmets with fittings and breastplate or any variation of these.

(6) Face Masks

- (a) The applicant should demonstrate that the design of the facepiece is adequate for its purpose and that it will properly seal against the diver's face to prevent leakage of water into the face mask or breathing gas to the environment.
- (b) The applicant should consider dead-space requirements, flow requirements of the system and the minimization of CO₂ buildup in designing the face mask.
- (c) Should a means be provided to drain the face mask in the event it becomes flooded during operation, activation of the drain should not result in the unsealing of the facepiece from the diver's face.
- (d) Where feasible, emergency and normal gas supply inlets should be located so that damage to, or failure of, one will not affect the use of the other.
- (e) A mouthpiece is the interface between the diver and the breathing-gas system. The applicant must show that the mouthpiece is adequate for its proposed use by means of test results or by acceptable history of similar use.

(7) Helmets

(a) Lightweight Helmets

- 1) Because of the many aspects of lightweight helmets that relate to diver safety, the applicant must justify in detail the adequacy of the helmet(s) for the intended mission(s).
- 2) The applicant should consider the following aspects as typical of those whose adequacy must be justified for the anticipated mission conditions.
 - a. Bail-out capability
 - b. Buoyancy, center of gravity and buoyancy moment on the diver
 - c. Compatibility of each helmet material with adjoining helmet materials, with sea water and with the anticipated breathing gases
 - d. Oil resistance, impact strength and biomedical compatibility
 - e. Snagging characteristics
 - f. Operability and flow characteristics of the valves
 - g. Ease of donning, fit on the diver's head and face, and effectiveness of helmet retaining system
 - h. Vision characteristics

- i. Ventilation and circulation design for controlling CO₂ and viewport fogging
- j. Effect of diver position on internal helmet pressure
- k. Noise characteristics of gas supply and exhaust
- l. Compatibility of communication system with helmet noise
- m. Interfaces of helmet with suit(s), gas lines and communication system
- n. Ear-clearing capability
- o. Protection against water leakage into helmet and gas leakage from helmet
- p. Ease of maintenance

(b) Deep Sea Diving Helmets

Helmets used with deep-sea, dry suit equipment should be designed to protect the diver's head during heavy underwater work. The helmet should be provided with an adequate means of securing it to the diving suit, with viewing ports that are located to insure adequate vision, with a means of controlling the inlet and outlet gas flows and with adequate communications.

f. Heating Systems for Divers

(1) A heating system may be required to maintain the diver's comfort and performance. Heat requirements are affected by water temperature, rate of work and the insulating properties of the diving suit. The applicant should justify by calculation and performance testing the adequacy of the diver heating system for the anticipated mission conditions.

(2) The applicant should consider the following aspects as typical of those whose adequacy must be justified for the diver heating system.

- (a) Size, weight and flexibility
- (b) Temperature distribution in diving suit
- (c) Heat capacity as related to mission requirements
- (d) Temperature regulation
- (e) Buoyancy characteristics
- (f) Effect of depth on system operation; i.e., insulating characteristics, heat and pressure loss in water-supply hose and voltage loss in electrical supply line

(g) Failure modes and emergency procedures

(h) Ease of maintenance and repair

(3) Heating and/or insulating the CO₂ absorbers in semi-closed and closed circuit breathing apparatuses may be necessary to insure an adequate operating life for the CO₂-absorbent material.

(4) Heating the diver's inspired gas becomes necessary for deep diving in cold water. The rate of respiratory heat loss increases as the temperature of the inspired gas is lowered, as the gas density increases with depth and as the volume of gas breathed increases with exercise.

(5) The minimum inspired gas temperature at a given respiratory minute volume (liters per minute) should be proportional to the operating depth and is defined in Figure B.1.

(6) The inspiratory gas heating system should also protect the diver from respiratory heat losses exceeding 350 watts at a given respiratory minute volume.

g. Waste Management

It is highly desirable that certain DSS have provisions for the storage, inactivation and disposal of waste products including human metabolic wastes, food and wash water wastes. Information on the deactivation chemicals used, a description of the system and a list of the design parameters used to size the storage facilities should be provided for review. Including a safety factor, water and sanitary plumbing lines should be designed for the maximum pressure to be used in the hyperbaric chamber. The applicant should provide evidence that all potential causes of leakage at design pressure have been considered and that adequate safety precautions have been incorporated into the design.

h. Food and Water Supply

Provisions for the storage and preparation of food, and purification and storage of drinking water should be given consideration by the prudent designer. Information to allow evaluation of the suitability of food storage and preparation facilities, a description of the water supply system including the cleanliness standards, purification chemicals used, and tests made to determine the solid, salt, and bacterial content of the drinking water should be considered.

i. Fire Fighting Equipment

The applicant should consider provisions for effectively fighting fires which may occur in the interior of a DSS.

If piping is used in the fire-protection system, it should be adequately sized not only to carry the required flow of extinguishing agent but to be reasonably immune to blocking by corrosion, deposits or contaminants which may find their way into the system. Strainers may be required to remove solid contaminants. A suitable flushing connection or connections should be provided. Drain valves and appropriate pitch of the associated piping may be required. Special care may be required to insure that the clear flow path through the system will not be obstructed during fabrication or welding. Gauge connections may be required, particularly near the nozzle or spray head calculated to have the least pressure under normal flow conditions. Where appropriate, protection against freezing should be provided.

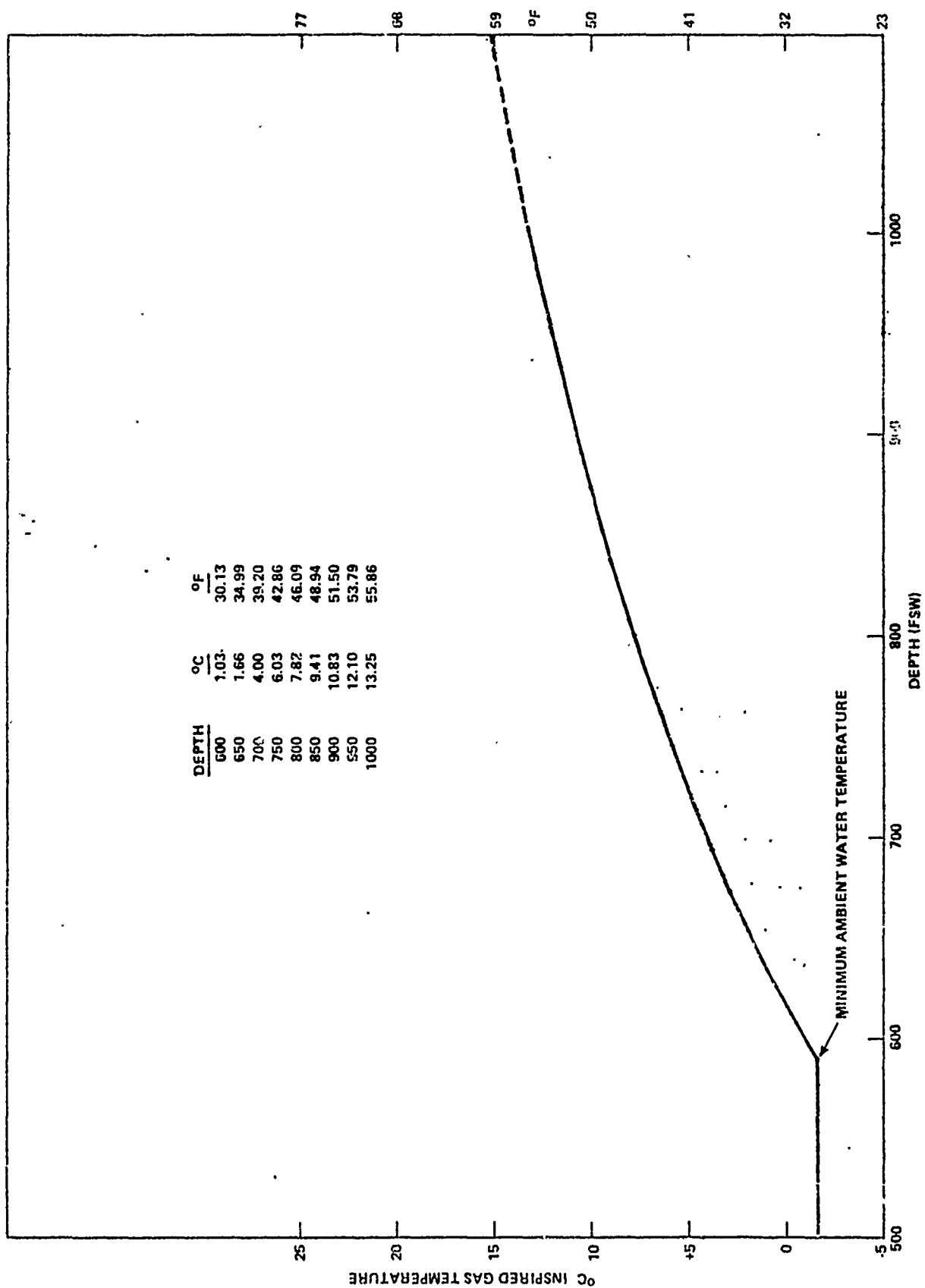


FIGURE B.1 STANDARD MINIMUM INSPIRED GAS TEMPERATURES

j. Communication Equipment

Communication facilities, such as radio equipment, underwater telephones and helium speech unscramblers, should be provided that are compatible with marine communications equipment for rescue and emergency communications.

The applicant should consider the necessity for a voice communication system that will permit DSS personnel and divers to communicate quickly with support personnel or with other divers.

Visual communication systems, such as lights and message boards, may be required. The applicant should specify the distance and water conditions for which these systems are appropriate.

B.5 TOXIC AND FLAMMABLE MATERIAL DESIGN CONSIDERATIONS

a. Toxic Materials

Materials, such as paints, insulation, adhesives, or equipment, instruments, fittings or other items containing material or components that would give off noxious fumes at its operating temperature or at any temperature below 200°F should not be installed or applied in manned spaces. For paint or adhesives, this requirement applies after drying or curing. Air sampling and analysis of the DSS's atmosphere for trace contaminants (see Appendix F for Guidelines) must be performed during simulated closed hatch operations to verify the above.

Mercury and beryllium or parts or components containing these metals should not be used in nor introduced into a DSS.

b. Flammable Materials

Every effort should be made to reduce or eliminate flammable materials from manned spaces. Flammable materials include materials in a form which will ignite or explode from an electric spark or from heating and which if so ignited, will independently support combustion in the presence of air or in an oxygen enriched atmosphere that might be encountered in the DSS under either normal or emergency conditions. A list of all known flammable materials must be forwarded for SCA review.

Magnesium and alloys containing magnesium should not be permitted inside the chamber because of their combustibility. Materials or combinations of materials that may produce sparks when struck together should not be used inside a DSS chamber. For instance, magnesium, aluminum and their alloys can produce sparks when struck against rusty steel.

Use of aluminum inside a steel chamber, or one having a steel floor, should be shown to be nonhazardous. Aluminum and its alloys should not be used for movable equipment, such as chair or cabinets, in a chamber with an exposed steel deck. Dragging equipment across the deck may remove by abrasion small particles of aluminum which may mix with rust to form a thermite mixture, thus creating a fire hazard.

DSS furniture, such as bunks and chairs, should be electrically conductive to minimize the probability of accumulation of a static electrical charge. However, these items should not be made of aluminum. Although bare aluminum is conductive, it tends to

leave unsightly stains on hands and clothing. Consequently, most aluminum that is to be handled is anodized. This anodized finish is highly insulating and blocks the desired electrical discharge path.

If aluminum paint is used inside a DSS, precautions should be taken to insure that it is not applied over rusted steel. A primer, not containing red lead or iron oxide, should be used under the aluminum paint.

The applicant should provide sufficient information to permit an independent evaluation of the suitability and adequacy of the materials used.

B.6 DESIGN OF CONTROL SYSTEMS, ELECTRICAL POWER DISTRIBUTION SYSTEMS AND LIGHTING SYSTEMS

B.6 . Introduction

This section covers general design criteria of control systems, electrical power distribution systems and lighting systems that are within the certification scope.

B.6.2 Control Systems

The applicant should furnish detailed design information for the respective control systems and components. This information should clearly discuss the liability of the system in the intended environment (e.g., temperature, pressure, humidity, etc.). System descriptions should be furnished for all control systems. In addition, the system descriptions should include an analysis of the consequences of a failure or loss of normal mode, and describe automatic and manual backup control features available for emergency recovery or surfacing procedures. Test data in support of system and component reliability for intended service should also be provided. Design information and test data should be in sufficient detail to permit an independent evaluation of the adequacy of the controls, in their environment, under all emergency operation conditions.

A control system is considered to be made up of three parts. The first part, the power supply, is the source of power from which the control derives its energy. The second part, the instrumentation, are the devices used to measure the variable being controlled, the devices used to measure the response of the control system and/or the devices used to provide necessary information to determine when the control should be actuated. The third part, control activators, are comprised of the devices which accomplish the desired control function.

a. Power Supply

Control power supplies may be manual, mechanical, pneumatic, hydraulic or electrical. The choice should be based on reliability in the environment in which the power supply must function. The applicant should furnish information which substantiates the reliability of the power supply in the intended environment. This information may be based either on previous use of the power supply or on tests.

Electrical equipment should be protected against voltage variations in the power supply and against excessive flow of current when such occurrences present a hazard--direct or indirect--to the DSS or to a diver.

All controls should have two independent sources of power. For purposes of discussion, these alternate sources of power are to be termed normal power and emergency power. Failure of one of the power sources should in no way hinder the use of the other power source. The emergency power source should be located such that it has as high a degree of survival as the personnel. In instances where redundant or backup electrical control circuits are provided to external equipment or safety devices, the circuits should be routed through different penetrators for maximum reliability. The emergency power should have, as a minimum, sufficient capacity to permit operation of systems and instrumentation to allow the DSS to safely ascend from maximum operation depth/pressure to the surface equivalent and to maintain the DSS at the surface equivalent. A load analysis should be furnished in sufficient detail to justify the power source capacity. This analysis should cover all possible combinations of power use.

Power supplies for diver electrical equipment - usually located on shore or ship, or in a habitat or personnel transfer device - are not considered as items of diver equipment. However, the applicant may consider rechargeable batteries as diver-mounted power supplies. Such a power supply should not be susceptible to power leakage.

Any electrical equipment to be carried or used by the diver should be specifically listed. The applicant should show that adequate precautions have been taken to prevent hazards.

b. Instrumentation

Instrumentation requirements in a DSS will vary widely depending upon depth and exposure times. For complex diving procedures, substantial instrumentation may be necessary. For short and shallow dives, less complicated instrumentation may be required. Generally, instrumentation includes all sensors, warning devices, and displays that are within the certification scope. Instrumentation may include, but not be limited to, the following:

- (1) Carbon-dioxide sensors
- (2) Oxygen sensors
- (3) Gas-flow sensors
- (4) Physiological sensors
- (5) Electrical-defect detectors
- (6) Heated-suit sensors
- (7) Respiratory gas-temperature sensors
- (8) Low-pressure warning devices

All instrumentation should provide response commensurate with the avoidance of hazardous conditions. The equipment should be electrically isolated from the DSS personnel and should not be subject to erroneous readout. The applicant should show that the equipment has sufficient accuracy and will operate satisfactorily within the range of design parameters. The applicant should specify the required accuracy of the measuring device consistent with control requirements.

In addition, the test data should be furnished which establishes the ability of the measuring device to meet the accuracy requirements in the intended environment. All measuring devices used to control should have a backup means for providing measurements. Failure of one measuring device should in no way impair the use of the other.

c. Control Actuators

The control actuator is any device or group of devices used to accomplish a desired control function. From a certification standpoint, the basic design goal of any control system within the certification boundary is reliability. To obtain reliability, the design should be such that the control actuator is not subject to false alarms or extraneous signals which produce undesired responses. Switches and controls that are used to manually energize a control actuator should be located so that they are not inadvertently energized.

Control actuators should be designed to fail safe. This is, failure of any portion of a control actuator should not in any way diminish the ability of the DSS to return to the surface. Indication of malfunction or failure in a control actuator should be provided to the operator or diver.

Individual control actuators should be capable of being isolated from other control actuators which share a common power supply. For electrical control actuators, this requires either fuses or circuit breakers on all lines connecting the control actuator to the power supply. For hydraulic or pneumatic control actuators, this requires appropriate check valve or valve isolation on all lines connecting the power supply to the control actuator.

Where a control actuator energizes more than one device to accomplish the desired control function, each device should be capable of isolation from the remaining devices. For electrical devices, this requires circuit protection for both supply and return lines as well as a device that can manually disconnect the load. For hydraulic and pneumatic devices, this requires appropriate check valves or isolation valves on supply and return lines.

Where a control actuator normally operates automatically, provision should be made to allow the operator or diver to manually control the actuator. The manual control should bypass as much of the control system as is practical.

B.6.3 Electrical Power Distribution Systems

a. Ungrounded Systems

All electrical power distribution systems should be ungrounded to minimize shock and fire hazards. Equipment connected to the power distribution system should not ground the power distribution system. All equipment designed to employ chassis grounds should be isolated from the electric power system by a transformer or suitable isolation device. To minimize corrosion due to electrolysis, the use of the hull/vessel as an electrical conductor or as a common reference should be avoided. For information relative to performing insulation resistance tests on electrical systems, see paragraph 6.3.3. Ground detectors should be provided when possible.

b. Fault Current Protection

Fault current protective devices should be provided for each unit of electric generating equipment or power supply and for each unit of power consuming equipment

connected to the distribution system. The design of the fault current protective devices should meet the basic requirements of Section 21.57 of AIEE Standard No. 45, "Recommended Practice for Electric Installation on Shipboard."

c. Cabling

Cable subject to deep submersible pressure should be either compensated or have a solid core construction. In addition, cable runs for individual feeders should be selected so that the effect of any fire damage due to a fault will be minimized with respect to damaging other cabling in the distribution system. Cable and wire housed inboard should be arranged or protected to eliminate damage during entry into, egress from or normal personnel movement within a DSS chamber. During DSS construction, installed cables should be protected against mechanical damage, burning by welders torches, and contact with oils and solvents. All cables terminating in pressure type connectors should have connectors applied in such a manner as to exclude all voids from the cable-connector assembly and to impose no undue mechanical stresses to minimize cable flexing during DSS transport and operations. A means of support should be provided at the cable/plug interface to minimize bending during DSS operation. Sufficient slack should be left in the cable at penetrators to permit plug-in and disconnect operations without stressing the cable excessively.

Cables and wires should be protected against damage by accidental contact, crushing, shearing or being used as a handhold. Cables should be nonwicking and should be shown to be capable of withstanding the operating pressure plus a safety factor.

Conductors should be flexible and easy to handle. Sufficient slack shall be left in the conductor at penetrators to permit plug-in and disconnect operations without excessive stress. Conductors should be supported, where possible.

Particular care should be taken in the case of portable electrical equipment to protect conductors from excessive flexure, kinking, tension, being caught between movable objects or being stepped on. Conductors should be resistant to such abuse.

Conductors within cables should be electrically insulated from each other, from the DSS and from the diver.

Electrical insulating materials should be selected on the basis of their ability to insulate the DSS equipment and to provide the proper functional and mechanical characteristics. Also, electrical insulating materials should be non-flammable and non-toxic. Examples of electrical functional characteristics are dielectric strength, insulation resistance and arc resistance. Mechanical properties include impact strength, tensile strength, elongation, flexibility, adhesion and abrasion resistance.

Connector design should permit the DSS operator or diver to disconnect the umbilical and any other electrical conductor readily without receiving an electrical shock. Electrical connectors should be sealed against water at operating pressure.

All cables terminating in pressure-type connectors should have connectors applied in such a manner as to exclude all voids from the cable-connector assembly and to impose no undue mechanical stresses on conductors or connections.

The materials and methods used to join connectors and fittings to umbilical cables and hoses should provide a strong bond capable of withstanding severe handling and operating conditions.

Connector pins and sockets should be corrosion resistant or plated to prevent corrosion and electrical discontinuities.

Electrical connectors should be designed to prevent incorrect connection. This may be accomplished by size selection, key fit or other means. Color coding or other visual identification alone is usually insufficient. Electrical connectors should also be designed to prevent accidental disconnect.

d. Electrical Shock Hazards

All electrical powered equipment or enclosures should be adequately grounded so as to prevent shock hazards to personnel.

e. Environment

The environment for electrical components that are used on DSS (e.g., cabling, connectors, protective devices, motors, power supplied) may differ markedly from normal shipboard conditions. The components may be oil immersed, subject to full sea pressure, operate at low temperatures, subject to high vibration, high humidity, etc. The applicant should furnish specific test information which justifies the ability of the electrical component to function in the intended environment for its design life or over the design range of pressures, temperatures, humidities, voltages, etc. For flammability and toxic considerations see Appendix B.5.

Materials used in electrical equipment should be shown, by test or experience, to be resistant to deterioration by the environment, by migration of a plasticizer or by the external application of heat.

f. Electrical Penetrators and Connectors

The body of electrical pressure vessel penetrators and connectors exposed to sea water should be of a corrosion resistant material.

Electrical cable pressure vessel penetrators must provide high water barrier at the hull to prevent flooding of the DSS in the event of failure of the external cable. Stuffing tube type penetrations of the pressure capsule or other hard structure are not generally acceptable. Pin type connections for cable entrances into compensated enclosures are preferred; however, terminal tube entrances are acceptable provided evidence of compatibility of the cable jacket and insulation with the compensating medium is provided.

Since the electrical hull penetrator is part of the primary pressure boundary, data should be provided to assure that its hydrocyclic life is defined in relation to the design life of the hull.

Provisions shall be made to protect the pressure vessel from corrosion in the gasketed areas of the penetrators.

B.6.4 Lighting Systems

The lighting system should have an alternate source of power or emergency lamps should be provided. These lamps are backup in the event of total loss of the normal lighting system. The capacity and location of the alternate power supply and the wattage rating of the emergency lamps should be specified.

B.7 NAVAL ARCHITECTURE DESIGN GENERAL REQUIREMENTS

The naval architectural requirements that the applicant should consider are at the least; static stability, both transverse and longitudinal, the conditions of list and trim, the strength of the DSS and the dynamic considerations of stability and motion of the DSS among waves.

B.7.1 Stability of a DSS

The applicant should demonstrate, where applicable, both by calculation and by tests, that a DSS has adequate static and dynamic stability under the various loadings and conditions encompassed by the design (e.g., surfaced, submerged and all possible emergency surfacing conditions). The designer should also identify any limiting conditions for sea state, winds, temperatures, water density variations, etc. Extreme loading conditions and the resulting stability should also be analyzed. For example, some DSS jettison relatively large weights to achieve buoyancy in an emergency. There is an attendant risk that significant weights might be jettisoned inadvertently while in normal operations. The applicant should show that the DSS would have adequate stability under these conditions also. The criteria of adequate stability and reserve buoyancy with sufficient information pertaining to stability must be furnished to operating personnel to permit proper control of loading and to avoid danger of capsizing or foundering in heavy seas or swells.

B.7.2 Surfaced Conditions

There are periods when certain DSS will be operational in a surfaced condition in the limiting sea state and wind conditions specified by the applicant. The applicant should show that the DSS is safe for emergency egress under these conditions. The applicant should also demonstrate that the DSS is adequate to withstand such factors as wave slap and that the strength of the structure of the DSS is adequate in the surfaced condition. Protection should be provided against foundering.

The DSS must be designed to operate on the surface in the most severe sea conditions specified by the applicant or the designer.

B.7.3 Inclining Experiments and Trim Dives for Submersibles, Submerged Habitats, Etc.

If the DSS is of such complex geometry that reliable curves of form cannot be readily calculated, air, surface and submerged inclining experiments must be performed to determine the stability in the surfaced and submerged modes. Precalculated form characteristics obviate the need for an air inclining experiment, hence the surfaced and submerged inclining experiments are sufficient to determine the stability surfaced and submerged when curves of form are available. Where the DSS vessel is not too large the longitudinal trimming moment could be determined by direct measurement or by a longitudinal inclining experiment. In addition, a trim dive is necessary to determine the proper weight and location of ballast, both permanent and variable, that will permit the vessel to operate under the design conditions of loading and in water of any density. The applicant should submit the inclining experiment and the trim dive results with the evaluation of the stability of the vessel.

B.7.4 Damaged Condition Information

The damaged condition criterion for a DSS design should be identified. The ability of a DSS to survive within the damaged condition criterion should be verified by calculation and testing, where possible. When "at-sea-testing" of a DSS's systems and/or components is impracticable, simulated tests using appropriate test fixtures may be substituted. The

means of detecting an abnormal situation or detecting a damaged condition should be evaluated. The corrective action intended by the designer should be implemented by written operating procedures. These actions should be demonstrated in simulated damaged conditions. The purpose of the demonstration is to verify the effectiveness, timeliness and realism of the proposed corrective actions established by the designer.

B.7.5 Strength of DSS

The applicant must show that the structural strength of certain DSS in a seaway does not endanger the safety of personnel. A DSS may operate in close proximity to the ocean bottom. This means that there will be a hazard of striking objects, grounding or even deliberate bottoming. There is also the hazard of bumping against or colliding with the surface support ship. The applicant should either show that a DSS can withstand such incident or demonstrate that sufficient precautions can be taken to avoid such situations.

B.7.6 Navigation Systems

Navigation equipment should enable the DSS operator or the diver to direct his course safely during operations. System accuracy should be based on worst-case operating conditions. An alternate or redundant mode of operation should be provided. Certain DSS should be provided with suitable navigation lights, where and when required.

B.7.7 Rescue Features

The features of the rescue capabilities included in the DSS design should be presented by the applicant. The DSS should be provided with the capability of being lifted for rescue or for recovery when flooded. As appropriate, a specific rescue plan should be included showing the intended means to accomplish rescue in the event of an accident while submerged. The limiting conditions for each of these operations should be included. The applicant should also state whether or not the DSS is compatible with existing U. S. Navy rescue and salvage equipment.

B.7.8 Stability and Buoyancy Systems

The applicant should identify the systems and components that provide any necessary stability and buoyancy for the DSS under operating conditions. An analysis of the consequences of a failure or loss of displacement by any of the buoyancy components should be included. The adequacy of specific materials should be justified as discussed in Appendix A.

APPENDIX C

DESIGN PARAMETERS FOR IMPLODABLE ITEMS

C.1 INTRODUCTION

This appendix contains guidelines on how to determine the criticality of systems and/or components which may implode and cause a casualty that would affect the safety of DSS personnel. Implodable systems and/or components exclusive of pressure hull/vessels and hard structure are divided into two categories:

I - Critical Volumes

II - Non-Critical Volumes

C.2 DEFINITIONS

a. Implodable Item - Any item containing a non-compensated compressible volume subject to full pressure.

b. Critical Volume - Any implodable volume which by imploding could cause a casualty to the DSS and/or which would affect the safety of DSS personnel.

c. Standoff Distance - The measured closest distance between the outer surface of the implodable item and the outer surface of the pressure hull/vessel component and/or system which could affect the material adequacy of the DSS.

d. Minimum Standoff Distance - The minimum distance at which an implodable item can be located such that if an implosion occurs it would not affect the material adequacy of the DSS (see Procedures C.3.2 below).

C.3 CRITICAL AND NON-CRITICAL VOLUMES

C.3.1 Method for Distinguishing a Critical Volume from a Non-Critical Volume

If an implodable volume is "non-critical" the testing as indicated in C.4 may not be necessary, subject to the SCA approval. Application of this method for distinguishing "critical volumes" and "non-critical volumes" is limited to the situation where the pressure hull is spherical. Additionally, even though the DSS pressure hull is spherical this method may not be applied (i.e., testing as indicated in C.4 must be followed) in the following cases:

a. Spherical pressure hulls/vessels with a design crush depth of less than 1.5 times the design depth.

b. Pressure hulls/vessels which are not designed to withstand ambient external pressure and 1 atm internal pressure.

c. Pressure hulls/vessels fabricated from a brittle material (e.g., glass, ceramics).

Procedures to cover these conditions should be generated by the applicant, as applicable.

C.3.2 Procedures for Determining Minimum Standoff Distance from a Spherical DSS Chamber

a. Calculate the "minimum standoff distance" in feet as described below:

- (1) Calculate the volume of the shell or pressure housing of the implodable item.
- (2) See figure C.1 with implodable volume and maximum design depth/pressure to obtain a "k" factor.
 - (a) If the depth/pressure is not exact take the next shallower depth/lower pressure (e.g., assume design depth 3500 feet in this case take 3000 feet).
 - (b) Any depth between 0-500 feet should be based on a 500 foot curve.
 - (c) If the implodable volume is less than 10 cubic inches assume a value of 10 cubic inches.
 - (d) If the implodable volume is greater than 1000 cubic inches, or depth is greater than 8,000 feet, testing indicated in C.4 shall be followed to assure the material adequacy of the item.
- (3) Multiply the k factor by $1/\sqrt{r}$ where r is the radius of the pressure hull/sphere in feet.
- (4) The result will be the "minimum standoff distance" in feet.

b. If the "minimum standoff distance" is greater than either:

- (1) The actual standoff distance between the implodable item and the pressure sphere or
- (2) The actual standoff distance between the implodable item and any system or components which if failed would affect the material adequacy of the DSS, then the implodable item is considered to have a "non-critical implodable volume."

c. If the "minimum standoff distance" is less than both:

- (1) The actual standoff distance between the implodable item and the pressure hull/vessel sphere and;
- (2) The actual standoff distance between the implodable item and any system or components which if failed would affect the material adequacy of the DSS; then the implodable item is considered to have a "non-critical implodable volume."

d. If the implodable item is found to have a "critical implodable volume," testing indicated in C.4 should be followed to assure the material adequacy of the item.

e. If the item is determined to have a "non-critical implodable volume" and it is therefore not considered necessary to test the implodable item to the requirements indicated in C.4, then, subject to the SCA's approval, testing may be eliminated. In this case, the following information is required:

(1) Sketches or photographs in the three mutually perpendicular planes described by x, y, z coordinates, showing the orientation of the implodable item with respect to all systems or components affecting the material adequacy of the DSS, for a distance of 3 "minimum standoff distances" in every direction from the implodable item.

(2) A general description (e.g., geometry, material) of the implodable item.

(3) Test depth and/or designed depth of the implodable item.

(4) Calculations of volume and "minimum standoff distance."

C.4 TESTING NECESSARY FOR "CRITICAL IMPLODABLE VOLUME"

The following tests are required for all implodable items considered by the SCA to have a "critical implodable volume."

a. Prototype testing necessary for implodable items fabricated from Category 3 materials (e.g., R&D prototype items).

(1) Static strength test (2 times maximum operating depth).

(2) Fatigue test - Full anticipated life cycle times four.

(3) Stress corrosion in sea water (run concurrently with fatigue test).

(4) Temperature and tightness test.

(5) Strength test prototype pressure container to collapse (in sea water) - Determine failure mode.

b. Testing necessary for all "critical implodable volumes" and "non-critical volumes" not treated as in paragraph C.3.2.e.

Submergence Pressure Test (Category 1, 2 and 3 components) to 1-1 1/2 times design operating depth for 10 cycles; 10 minutes at greatest pressure - cycles 1-9, 1 hour at greatest pressure - cycle 10, (35°F sea water if practicable).

Leakage or visible signs of external damage shall be cause for test failure.

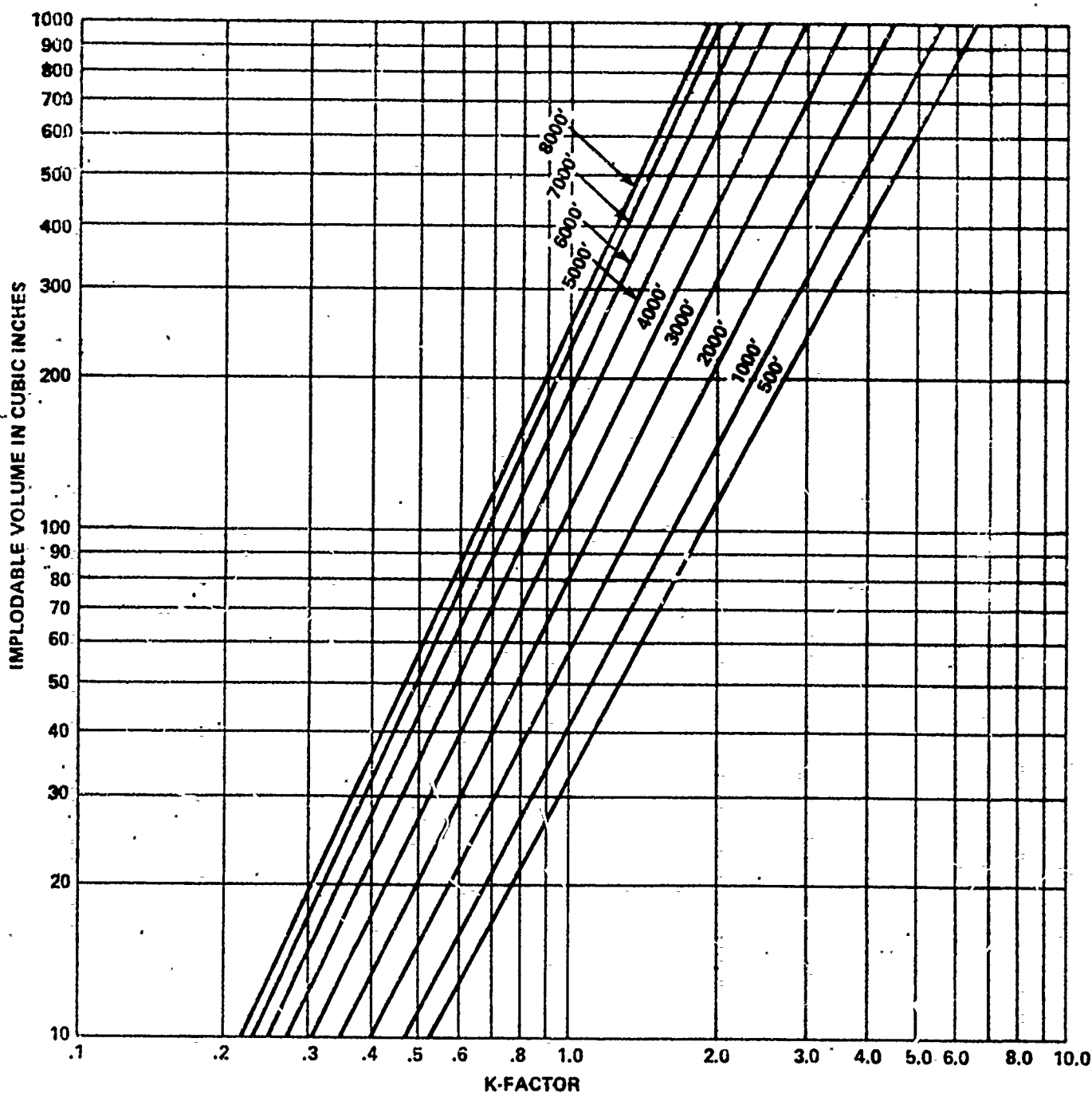
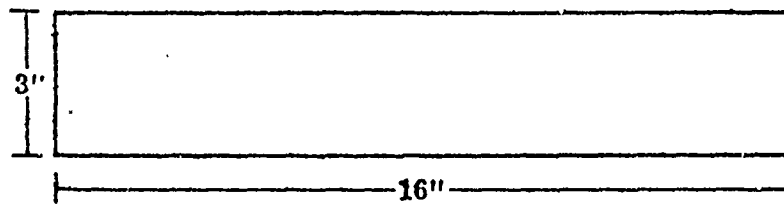


FIGURE C.1 MINIMUM STANDOFF DISTANCE FOR IMPLODABLE ITEMS
(SPHERICAL PRESSURE HULL)

MINIMUM STANDOFF DISTANCE FROM A SPHERICAL DSS
FOR AN IMPLODABLE CAMERA CASE



1. CALCULATE INSIDE VOLUME

$$V = \pi (3/2)^2 \times 16$$

$$V = \pi (9/4) \times 16 = 36 \times \pi = 113 \text{ CUBIC INCHES}$$

2. ENTER GRAPH UNDER MAXIMUM DESIGNED DEPTH OF 6000' AND VOLUME OF 113 CUBIC INCHES TO GET K-FACTOR.

$$K \sim .85$$

3. MULTIPLY K-FACTOR BY $\frac{1}{\sqrt{R}}$ WHERE R IS THE PRESSURE HULL RADIUS IN FEET.

$$R = 3.5' \rightarrow (3.5)^{1/2} = 1.87$$

$$\text{MINIMUM STANDOFF DISTANCE} = \frac{.85}{1.87} = .455$$

$$\text{MINIMUM STANDOFF DISTANCE} \cong 5-1/2"$$

THIS IS THE MINIMUM STANDOFF FOR CONSIDERING AN ITEM OF "NON-CRITICAL VOLUME". TESTING PER PARA - GRAPH C.3 WOULD NOT BE REQUIRED AS LONG AS THE HULL STANDOFF IS GREATER THAN 5 1/2" AND THE ITEM IS NOT LOCATED WITHIN 5 1/2" FROM ANY CERTIFICATION SCOPE ITEM.

Figure C.2 SAMPLE CALCULATION (ASSUME SPHERICAL DSS HAS 6000 FT. MAXIMUM DESIGN DEPTH)

APPENDIX D

DESIGN PARAMETERS FOR EXPLODABLE ITEMS

D.1 INTRODUCTION

During the design process particular attention shall be given to the shock effects produced by the explosion of items within the DSS.

Many devices are subject to inadvertent explosion during decompression because they have been infiltrated by helium or other gases during a compression cycle. These devices, in themselves, may become hazards within the DSS and should be considered during the design process.

At the present time there is no known analytical method for determining the material adequacy of items within a DSS which may explode and cause a casualty. Therefore, in order to achieve a maximum reasonable level of assurance for these items this appendix contains guidelines to determine their material adequacy.

D.2 DESCRIPTION AND ORIENTATION

Data of the manned DSS spaces should be reviewed to determine and describe the size, quantity and locations of all explodable volumes. Representative samples of these items should be selected based on the following Sampling Table and subjected to the test procedure of D. 3.

Sampling Table

<u>Lots or Batch Size</u>	<u>Sample Size</u>
2 to 8	2
9 to 15	3
16 to 25	5
26 to 50	8
51 to 90	13
91 to 150	20

D.3 PROCEDURE

Each item selected should be tested as follows:

a. Subject the item to a pressurized helium soak test. The time of soak should be not less than two times the maximum expected exposure period. The pressure should be the maximum operating pressure.

b. Following the soak test, depressurize at a rate not less than 1.5 times the maximum depressurization rate of the manned space.

D.3.1 Acceptance Criteria

That items do not show evidence of physical deterioration should be cause for acceptance of all like items. Accepted items may be used in manned spaces.

D.3.2 Rejection Criteria

That items show evidence of physical deterioration shall be cause for rejection of all like items.

D.3.3 Retest

Further analysis and/or retesting of rejected items will be subject to SCA approval.

D.4 NON-METALLIC MATERIALS

It should be shown that non-metallic materials that are to be exposed to high-pressure helium do not deteriorate due to exposure to the maximum design rate of helium decompression.

APPENDIX E

DEEP SUBMERGENCE SYSTEMS BREATHING GAS REQUIREMENTS

E.1 INTRODUCTION

The composition of breathing gas and the quantity required are determined by physiological characteristics of the human body.

The breathing mechanisms that serve to regulate partial pressures of oxygen and carbon dioxide in the blood at sea level serve equally well under the sea if the partial pressures of oxygen and carbon dioxide, as well as the respiratory volume, are similar to those at sea level. Sufficient information is known regarding physical tolerance to partial-pressure levels to permit safe selection of both composition and volumes of breathing gas for a DSS.

E.2 BREATHING GAS CONSUMPTION

Breathing gas is a mixture containing oxygen, part of which is consumed in respiration, and inert diluent gas, such as nitrogen or helium, that is not consumed or altered. The oxygen consumed in the body reacts with carbon and hydrogen to produce CO_2 and water. The CO_2 and water (which appears as water vapor) thus formed are exhaled with the breathing gas. The volume fraction of CO_2 released relative to the volume of oxygen consumed varies from 0.7 to 1.1 depending upon the carbon-hydrogen ratio of food being metabolized, exertion history and other factors.

Figure E.1 relates oxygen mass consumption rate and respiratory volume to rate of exertion. The data for Figure E.1 are based on experimental measurements (2,3)* provide a basis for selection of breathing gas quantities for DSS.

The mass rate of oxygen consumption and the corresponding carbon dioxide production rate vary with physical exertion but are independent of depth. As indicated in Figure E-1, values of oxygen consumption vary from about 0.5 standard liters per minute (slm) when at rest, to about 4.0 slm with heavy exertion. These values are equivalent to 0.0895 and 0.716 pounds of oxygen per hour, or 1.14 to 9.13 standard cubic feet (scf) per hour.**

The volume of oxygen consumed decreases in inverse proportion to absolute pressure (depth) in accordance with gas laws.

The values for respiratory minute volume (RMV) (the volume of gas moved through the lungs in one minute) shown in Figure E-1 depend upon ventilation (removal of carbon dioxide) requirements of the body. These volumes are the same at all diving depths. Thus, the mass flow of gas to meet ventilation requirements increases with depth (pressure) and with oxygen consumption (exertion).

In demand-type breathing apparatus, the averaged volumetric breathing gas supply rate equals the RMV requirement of 10 to 100 lpm (0.3 to 4 cfm), depending upon the level of exertion, measured at depth. The instantaneous flow rates tend to conform to the user's breathing demands.

In closed-circuit rebreathing apparatus supplied with pure oxygen, the rate of oxygen consumption is equaled by the rate of supply, all carbon dioxide being absorbed in the recirculation loop and no gas being vented from the apparatus. The oxygen mass consumption

References are given at the end of Appendix E.

* The standard liter is defined at 0°C (32°F) and the standard cubic feet is defined at 60°F . Thus, although 1 ft^3 23.3 liters, one standard ft^3 26.3 standard liters.

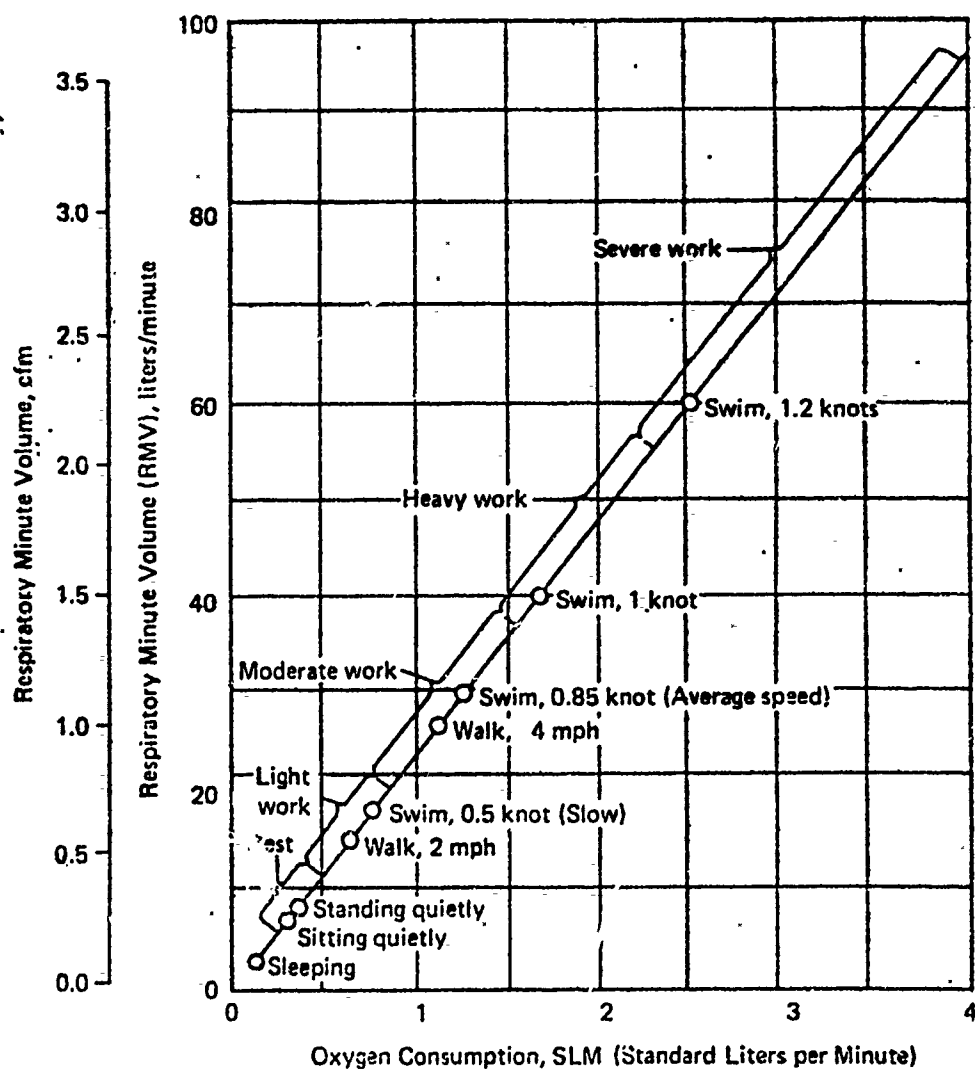


FIGURE E.1 RELATION OF RESPIRATORY VOLUME AND OXYGEN CONSUMPTION TO TYPE AND LEVEL OF EXERTION⁽³⁾

rate depends only upon the rate of exertion and is independent of depth (recognize, however, that it is necessary to maintain a certain minimum volume of gas in the recirculation loop). Oxygen consumption rates can range from 0.5 to 3 slm, and an average value of 1.5 slm appears reasonable for planning purposes.

Semiclosed-circuit mixed gas breathing apparatus operate by chemically removing the CO_2 from most of the gas mixture exhaled by a diver. This CO_2 -free portion of the exhaled gas mixture, which is somewhat depleted of oxygen, is mixed with an inflowing gas mixture that is rich in oxygen, forming a total mixture that is intermediate in oxygen content. The oxygen content and the mass flow rate of the inflowing oxygen rich mixture are preselected so that the oxygen content of the total mixture is, within acceptable limits, the same as that of the gas mixture that the diver had originally inhaled - this total mixture can now again be inhaled. The part of the gas mixture exhaled by the diver that still contains CO_2 is vented from the apparatus to make room for the inflowing oxygen rich gas mixture. In the particular semiclosed-circuit breathing apparatus used in saturation-diving excursions, the oxygen rich gas mixture contains a 1.2 atm partial pressure of oxygen at the diver's depth and the mass flow rate is sufficient to provide for continuous exertion at 3 slm oxygen usage. The oxygen concentration in the inhaled gas mixture varies from about 1.0 atm at rest to 0.21 atm during severe exertion. The vented gas contains oxygen at partial pressures varying from 0.8 atm at rest to 0.16 atm during heavy exertion. The mixture and mass flow rate of gas into the system are selected on the basis of depth and the maximum short time oxygen partial pressure exposure allowable should the diver find it necessary to flood his apparatus with this oxygen rich mixture.

Certain DSS, such as habitats, chambers and the standard deep sea diving apparatus, dilute the carbon dioxide rich exhaled gas in the system to bring it to non-toxic, breathable levels of 0.01 to 0.025 atm partial pressure of carbon dioxide. The required flow rate into this type of system is similar to the RMV at maximum exertion. In these systems it is usual to supply at least 4.5 cfm (127 lpm) of gas, per diver, measured at depth. This would be sufficient to permit exertion levels corresponding to oxygen consumption of 1.27 slm if carbon dioxide in the system is held to a level of 0.01 atm partial pressure, or of 3.0 slm if carbon dioxide in the system is held to a level of 0.024 atm partial pressure.

The surface-supplied helium-oxygen deep sea diving apparatus operates much like the semiclosed-circuit apparatus in that breathing gas in the helmet is recirculated through a carbon dioxide absorber to minimize volumetric gas inflow requirement. Breathing gas is supplied from the surface through a hose at a rate of 0.5 cfm, measured at depth, and enters the helmet through an ejector which drives the recirculation flow. With a recirculation ratio of about 10, the ventilation effect is equivalent to 5 cfm or 140 lpm, which is adequate for heavy work. The oxygen content of the mixture is maintained at a high level and can be varied during the dive to suit depth and decompression requirements. If this apparatus is used at shallow depths with air, anoxia could result unless the flow rate into the helmet is increased to provide needed oxygen. The required flow rate will reach 2.1 scfm of air at the surface for oxygen consumption of 3 slm.

There are certain equipments in use that employ a breathing gas flow to a rigid helmet or mask that does not possess a flexible gas storage capability such as is provided by a breathing bag or as in the case of the standard deep sea diving apparatus, the bib of the diver's dress. If the diver's physiological functions are not to be significantly affected, it is necessary, in these equipments, to match the gas flow rate into the helmet or mask with the user's instantaneous peak inhalation flow rate. Information available at this time places this flow rate in the neighborhood of 350 lpm (12.4 cfm) measured at depth.

The efficiency of oxygen utilization or percentage of the oxygen supplied that is utilized, varies with the type of DSS and with depth. When breathing air at sea level, oxygen content is reduced from 20.8 percent in inspired air to 16.6 percent in vented air, utilizing only 20.2 percent of the available oxygen. When using demand-type open-circuit breathing apparatus supplied with air, or with a gas mixture of constant oxygen content, the mass flow of breathing gas, and of the oxygen in it, will increase with depth while the oxygen consumption remains constant. Thus, a lower percentage of the oxygen supplied will be utilized as depth increases. If, however, the breathing apparatus were to vary oxygen content of the breathing gas with depth to provide a constant oxygen partial pressure, the mass flow of oxygen supplied would be constant and the proportion of oxygen utilized would be constant. In semi-closed breathing apparatus where oxygen is supplied at 1.2 atm partial pressure, recirculated and finally vented at 0.166 atm partial pressure, 86 percent of the oxygen supplied is utilized during heavy exertion. Finally, with a closed system supplied with pure oxygen, all of the oxygen supplied would be utilized, since no gas is vented and the oxygen is recirculated until it is used.

TABLE E-1. EFFECTS OF VARIOUS O₂ CONCENTRATIONS

O ₂ Concentration Partial Pressure Atmospheres	Effect
0.18-.21	Normal sea-level conditions
0.16-.12	Increased breathing rate, lack of coordination
0.14-.10	Easily tired; easily upset emotionally; possible loss of pain or injury; abnormal fatigue from exertion
0.10-.06	Lethargic; apathetic; confused thinking; physical collapse; possible unconsciousness, nausea and vomiting
0.06 or less	Convulsive movements, gasping, cessation of breathing

E.3 SURFACE BREATHING AIR REQUIREMENTS

The volume of breathing gas (air) needed for a DSS operating at one atmosphere may be determined using Figure E.1 and taking into consideration the total of all aspects of DSS personnel activity.

E.3.1 Human Oxygen and Air Consumption

The normal oxygen control range should be 18-21%. Alarm set points should be 17-23%. If the alarm limits are exceeded immediate corrective action should be taken. (Because of fire prevention considerations, if the concentration of oxygen ever exceeds 25% or if the corrective action fails to return the oxygen concentration to within the limits the DSS should be immediately returned to the surface and ventilated.)

E.3.2 CO₂ Production Rates - Respiratory Quotient (RQ)

Respiration accounts for most of the carbon dioxide generated in a DSS. With an average oxygen consumption of 1.0 SCFH (.44 SLPM) per man, the corresponding average CO₂ generation rate has been observed to vary between 0.80 and 0.85 SCFH (0.352 and 0.374 SLPM) depending upon dietary considerations. This is equivalent to 0.1 lbs./man-hour. Since the specific gravity of CO₂ is equal to 1.53; the respiratory quotient, RQ, is equal to the volume of CO₂ produced for each unit volume of O₂ consumed.

Therefore:

$$RQ = \frac{\text{Volume of CO}_2 \text{ produced}}{\text{Volume of O}_2 \text{ consumed}} = \frac{0.85}{1} = 0.85$$

E.3.3 CO₂ Build Up

Without removal equipment, CO₂ concentration will increase in accordance with the following formula:

$$\% \text{ CO}_2 = 0.03 + \frac{(RQ) \times \text{O}_2 \text{ (Consumption rate)} \times T}{V/N}$$

Where T = Time in Hours

V/N = Floodable Volume Per Man

RQ = Respiratory Quotient

0.03 = % of CO₂ in "Clean" Air

E.3.4 Toxicity of Carbon Dioxide

In normal breathing, the concentration of oxygen in the breathing gas is reduced and the oxygen is replaced by a nearly equal volume of carbon dioxide. If carbon dioxide is included in the inhaled gas, the partial pressure of carbon dioxide in the blood increases, and the respiratory center in the brain increases ventilation (tidal volume and/or breathing rate) to restore normal carbon dioxide levels. Excessive amounts of carbon dioxide in the breathing gas result in toxic effects, the severity of which depend upon exposure time and the partial pressure of carbon dioxide.

Figure E-2 shows the relation of physiological effects of carbon dioxide for different concentrations and exposure periods. In Zone I no perceptible physiological effects have been observed. In Zone II small threshold hearing losses have been found and there is a perceptible doubling in depth of respiration. In Zone III, the zone of distracting discomfort, the symptoms are mental depression, headache, dizziness, nausea, "air hunger," and decrease in visual discrimination. Zone IV represents marked physical distress leading to dizziness and stupor, with inability to take steps for self-preservation. The final state is unconsciousness.

The bar graph at the right of Figure E.2, for exposures of 40 days, shows that concentrations of carbon dioxide in air of less than 0.5 percent (Zone A) cause no biochemical or other effects, concentrations between 0.5 and 3.0 percent (Zone B) cause adaptive biochemical changes, which may be considered a mild physiological strain, and concentrations above 3.0 percent (Zone C) cause pathological changes in basic physiological functions.

For normal DSS operations, CO₂ removal rates should be provided that result in carbon dioxide partial pressures corresponding to Zones I and II for short-term exposure, and to Zones A and B for long-term exposures.

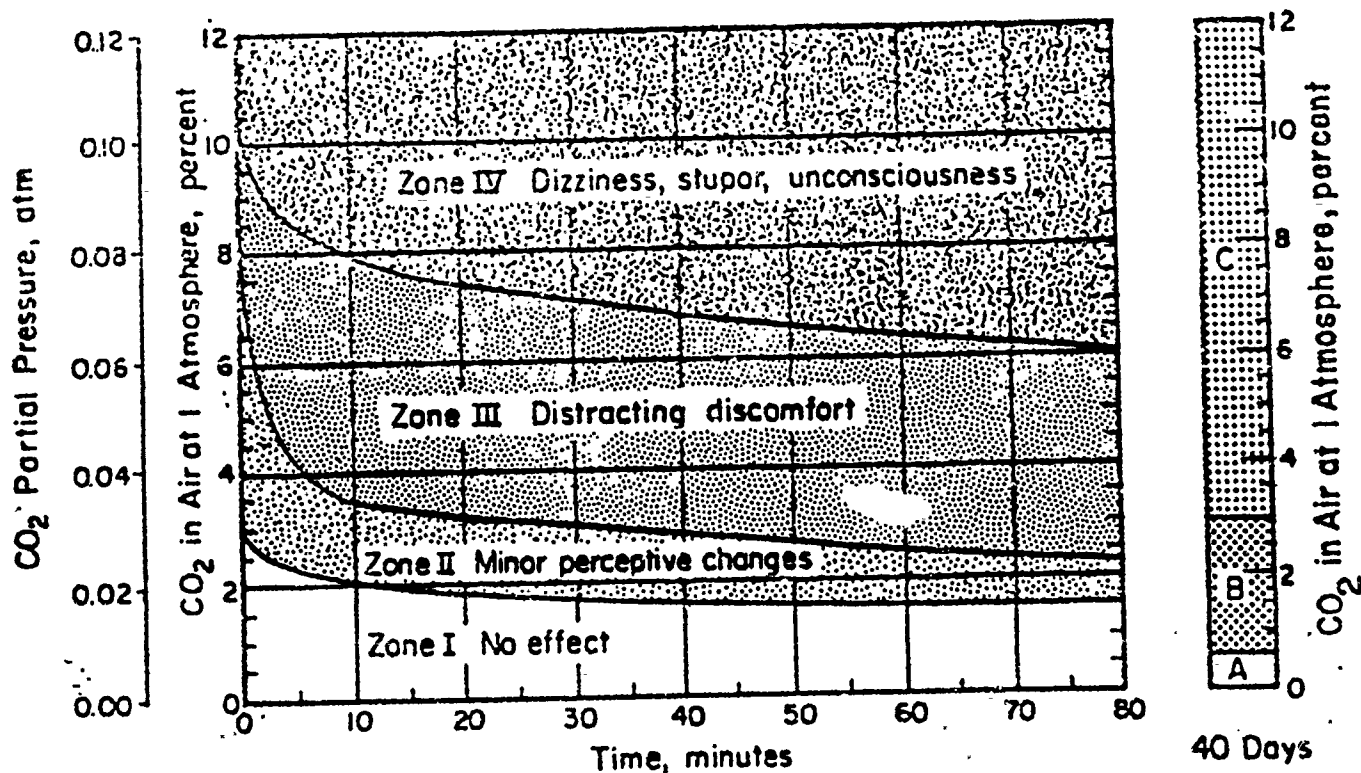


FIGURE E.2 RELATION OF PHYSIOLOGICAL EFFECTS TO CARBON DIOXIDE CONCENTRATION AND EXPOSURE PERIOD

E.3.5 Maximum CO_2 Operating Limits

It is recommended that the short time exposure limit of CO_2 be 0.015 atmospheres partial pressure with 0.02 atmospheres partial pressure indicating an immediate dire emergency.

E.3.6 Trace Contaminants

In addition to Table E-2, below, BUMED Instruction 6270.3D dated 15 February 1966 lists the Threshold Limit Values for toxic materials as adopted by the American Conference of Government Industrial Hygienists.

The Threshold Limit Values refer to air-borne concentrations of substances and represent conditions under which it is believed that nearly all workers may be repeatedly exposed, day after day, without adverse effects. Since the TLV levels are based on an 8-hour day, 40-hour work week, they tend to represent the upper limits for most operational, one-atmosphere, DSS.

TABLE E-2. LIMITS FOR ATMOSPHERIC CONSTITUENTS
(Limits in PPM by Volume unless otherwise noted)

Chemical Substance	90-Day Limit	24-Hour Limit	1-Hour Emergency Exposure Limit	Remarks
1. Acetone	300	2000	*	Set at approximately 1/4 of lower explosive limit of 2-1/2%.
2. Acetylene	6000	6000	6000	
3. Acrolein	*	*	*	
4. Ammonia	25	50	400	See Item 15 (a).
5. Arsine	0.01	0.1	*	
6. Benzene	1.0	100	*	
7. Carbon Dioxide	3.8 mm Hg	7.6 mm Hg	19 mm Hg	Equivalent to 1/2% and 1% and 2-1/2% at 760 mm Hg.
8. Carbon Monoxide	25	200	200	
9. Chlorine	0.1	1.0	*	
10. Dichlorodifluoromethane (Refrigerant 12)	200	1000	2000	Set by decomposition products formed in CO-H ₂ burner.
11. Dichlorodifluoroethane (Refrigerant 114)	200	1000	2000	Set by decomposition products formed in CO-H ₂ burner.
12. Ethanol	100	500	*	See Items 10, 11 and 37.
13. Formaldehyde	*	*	*	
14. Freon Refrigerants	—	—	—	
15. Hydrocarbon Solvents	—	—	—	Principal sources include: paint thinner, lighter fluid, mineral spirits, etc.
(a) Benzene	3 Mg/M ³	300 Mg/M ³	*	Equivalent concentrations in PPM are listed under Item 6.
(b) Total Aromatics (less Benzene)	10 Mg/M ³	*	*	
(c) Total Aliphatics (less Methane)	60 Mg/M ³	*	*	
16. Hydrogen	10,000	10,000	10,000	Set at approximately 1/4 of lower combustible limit of 4%.
17. Hydrogen Chloride	1.0	4.0	10	
18. Hydrogen Fluoride	0.1	1.0	8	
19. Hydrogen Sulfide	*	*	50	
20. Isopropanol	50	200	*	Set at approximately 1/4 lower explosive limits of 5.3%.
21. Mercury	0.01 Mg/M ³	2.0 Mg/M ³	*	
22. Methane	13,000	13,000	13,000	
23. Methanol	10	200	10	Based on decomposition in CO-H ₂ burner.
24. Methyl Chloroform (1, 1, 1 Trichloroethane)	2.5	10	25	
25. Monoethanolamine (MEA)	0.5	3.0	50	
26. Nitrogen Dioxide	0.5	1.0	10	Physiological lower limit, fire safety upper limit.
27. Oxygen	140-160 mm Hg	140-160 mm Hg	*	
	Not exceeding 21% by volume.	Not exceeding 21% by volume.		
28. Ozone	0.02	0.1	1.0	See Hydrocarbon Solvents, Item 15.
29. Paint Thinner	—	—	—	
30. Phosgene	0.05	0.1	1.0	
31. Phosphine	*	*	*	
32. Stibine	0.01	0.05	*	
33. Sulfur Dioxide	1.0	5.0	10	
34. Triaryl Phosphate	1.0 Mg/M ³	50 Mg/M ³	*	See Item 24.
35. 1, 1, 1 Trichloroethane	—	—	—	
36. Trichloroethylene	*	*	*	
37. Trichloromonofluoromethane (Refrigerant 11)	5	20	50	
38. Vinylidene Chloride	2.0	10	25	

* Limit has not been established.

E.3.7. Atmosphere Analysis for Trace Contaminants

The applicant should have samples of the DSS's atmosphere analyzed for trace contaminants and the results forwarded to SCA for review. The analysis should be performed during simulated closed hatch operations.

An analysis should be performed for initial certification and, thereafter, whenever the vehicle undergoes a major overhaul or has its interior repainted or cleaned with solvents that contain hydrocarbon or other toxicants. Appendix F gives guidelines for atmosphere evaluations.

E.4 COMPRESSED BREATHING AIR REQUIREMENTS

Some DSS are used for light activity to moderate depths using air as the breathing gas. The breathing air is supplied in the DSS from low to medium pressure air compressors or from banks of flasks that have been charged by high pressure air compressors.

Important factors to be considered in the design of compressed air breathing systems are:

- a. Ventilation-air flow rates
- b. Pressure requirements
- c. Air compressor design
- d. Environmental effects on compressor capacity

E.4.1 Breathing Air Purity Requirements

The U. S. Navy Bureau of Medicine and Surgery has established purity requirements* for breathing air as follows:

Oxygen	20 to 22 percent by volume
Carbon dioxide	300 to 500 ppm (0.03 to 0.05 percent by vol.)
Carbon monoxide	20 ppm maximum
Oil, mist, and vapor	5 mg/m ³ maximum
Solid and liquid particles	Not detectable except as noted above under oil, mist, and vapor.
Odor	Not objectionable

In order to meet these requirements it is necessary either to use special nonlubricated compressors, or to pass air from standard compressors through efficient contaminant elimination systems. The compressed air provided for general shipboard services is usually not adequate for use as breathing air without additional processing, as it usually contains excessive amounts of oil. Additionally, air taken from machinery spaces or from down-wind of the exhaust of an engine or boiler may contain excessive concentrations of carbon dioxide, carbon monoxide and other toxic trace contaminants.

E.4.2 Trace Contaminants

When a DSS is supplied with air from compressors at the surface there is always danger that some carbon dioxide may find its way into the compressor inlet. Exhaust gas from shipboard engines or from motor traffic in harbor areas can result in significant air contamination. If the compressed air contains 0.25 percent carbon dioxide it contains half the Zone 2 toxic limit of 0.5 percent at 5 atm pressure (130 feet depth). Thus, only half of the air supplied is useful as diluent for carbon dioxide generated by the DSS personnel's respiration, and the quantity of air supplied must be doubled to avoid toxic reactions. Thus, it is extremely important to assure that clean, fresh air is piped to the compressor inlet, and that the inlet is not downwind from sources of carbon dioxide.

* BUMED Letter Serial 606 of 7 June 1969

Normal atmospheric air contains small concentrations of toxic gases, including sulphur dioxide, oxides of nitrogen and gaseous hydrocarbons, and particulates. The levels at which these contaminants are found are usually well below those at which DSS personnel comfort or performance would be affected, even when it is considered that the effect of pressure is to increase the partial pressure, and thus the effect, of such contaminants.

Most of the toxic trace contaminants in the atmosphere originate from the exhaust of internal-combustion engines and other high pressure high temperature combustion. Exhaust-fumes are detected readily by monitoring for CO_2 which is the major constituent of such combustion products.

Trace contaminants can also enter the breathing system in the form of compressor lubricant, solvents used for cleaning breathing equipment, and out-gassing of absorbed solvents from hoses, masks, and other rubber or plastic components of breathing systems. These contaminants can originate from the manufacturing process, be absorbed during storage, or be introduced during routine cleaning and maintenance of equipment. Particular care must be exercised to assure that any solvents used in cleaning of diving equipment are compatible with the construction materials and also that they can be removed satisfactorily. For example, when a Freon TF cleaning agent is used in nylon-lined DSS umbilical hose, the hose absorbs large quantities of the cleaning agent that cannot be removed and which subsequently out-gasses during use.

E.5 HYPERBARIC BREATHING GAS REQUIREMENTS

While much remains to be learned with regard to the physiology of life at elevated atmospheric pressures, the following information is provided for guidance. Since new information is becoming available at an increasing rate, the following parameters should not be considered all-inclusive and sponsors of manned hyperbaric systems should attempt to remain knowledgeable of the current extent of the state of the art.

E.5.1 Oxygen Concentrations

Excessive oxygen in a subject's blood will cause a toxic reaction. On the other hand, insufficient oxygen in a subject's blood will result in unconsciousness. The amount of oxygen that goes into the blood is directly related to the partial pressure of oxygen in the subject's breathing gas mixture. Neglecting other effective factors, such as time of exposure, the inert gas in the breathing gas mixture and exertion, it can be initially assumed that an acceptable breathing medium (gas mixture) must expose its user to not less than 0.16 atmospheres, partial pressure, and not more than 2.0 atmospheres, partial pressure, of oxygen. On this basis it can be seen that, using a breathing medium of compressed air (~21% O_2 , ~78% N_2 & ~1% other), a diver could be expected to experience oxygen toxicity on a dive deeper than about 280 feet (9.5 atmospheres, absolute, total pressure). On the other hand, if in some way, the amount of oxygen in the compressed air was reduced in order to dive deeper, the diver could be expected to become unconscious when at very shallow depths (obviously this is an over-simplification of the situation; for instance, compressed air is unsatisfactory as the breathing gas mixture in dives deeper than 190 feet because the partial pressure of nitrogen in the air at such total pressures produces a narcotic effect to the diver that significantly limits his mental acuity). The point to be made is that, to achieve dives to depths much deeper than about 200 feet, it is necessary to alter the composition of the diver's breathing gas mixture as his depth increases and decreases in order to keep the partial pressure of oxygen to which he is exposed within acceptable limits.

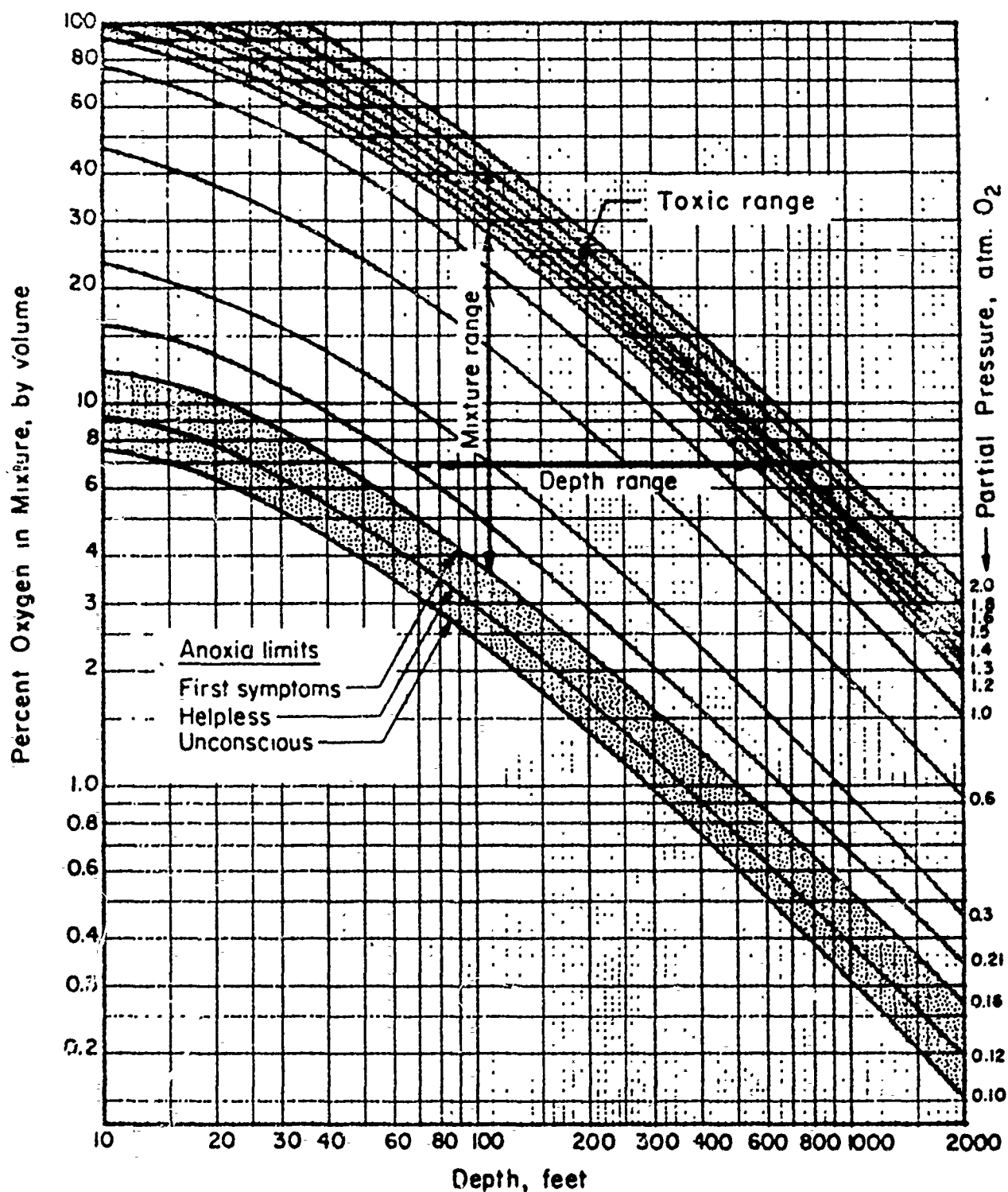


FIGURE E.3 PERCENTAGE OF OXYGEN IN BREATHING MIXTURE AS A FUNCTION OF DEPTH AND OXYGEN PARTIAL PRESSURE

$$\text{Percent O}_2 = \frac{\text{Partial pressure O}_2 \text{ atm} \times 100}{\text{Seawater pressure, atm}}$$

Figure E.3 relates the percentage of oxygen in a breathing mixture to depth and to oxygen partial pressure. A large area within which mixtures are physiologically acceptable for a few hours is bounded on the lower side by curves defining different levels of anoxia (oxygen deficiency) and on the upper side by curves of increasing oxygen toxicity. It will be noted in Figure E.3 that the first symptoms of anoxia occur when oxygen partial pressure falls to 0.16 atm, and that DSS personnel become helpless when oxygen partial pressure drops to 0.12 atm.

In the region of high oxygen concentration, toxic effects on the central nervous system, leading to convulsions and unconsciousness, limit the duration of exposure at oxygen partial pressures above 1.2 atm. The actual allowable duration of exposure is reduced by CO₂ in the inspired gas and by exertion, and varies somewhat with the mission and with the type of DSS.

Table E-3 summarizes time limits for working dives, as influenced by oxygen partial pressure and type of DSS. Limits established for surface-supplied DSS in which significant CO₂ levels are present in the inspired gas, are significantly lower than for the closed and semiclosed systems, in which no CO₂ is inspired. The exceptional exposure table should only be used in extreme emergencies, as discussed in the U. S. Navy Diving Manual, and is not suitable for normal operations.

TABLE E-3. TIME LIMITS FOR WORKING DIVES, AS INFLUENCED BY OXYGEN PARTIAL PRESSURE AND TYPE OF BREATHING EQUIPMENT

Time limit, Minutes	Normal operations	Exceptional exposure	He-O ₂ SCUBA semiclosed	Pure Oxygen SCUBA	He-O ₂ Saturation Umbilical, Semiclosed
240	1.0	1.3	1.3	1.3	1.2
180	--	1.4	1.4	1.4	--
120	1.1	1.5	1.5	1.5	--
100	--	1.6	1.6	1.6	--
80	1.2	1.7	1.7	1.7	--
60	1.3	1.8	1.8	1.8	--
50	1.4				
40	1.5	1.9	1.9	1.9	--
30	1.6	2.0	2.0	2.0	--

Data of Table E-3 are based on experience at depths to 200 ft. At greater depths, the U. S. Navy presently prefers to limit oxygen partial pressure to 1.2 atm.

In saturation diving, with exposure periods measured in days, the limiting oxygen exposure is imposed by lung irritation and eventual lung damage, which is believed to occur with oxygen partial pressure of 0.6 atm or more. To avoid such effects, the oxygen partial pressure in currently operational U. S. Navy saturation diving systems has been limited to the range of 0.3 to 0.35 atm. Limited experience by others with partial pressures up to 0.5 atm has been satisfactory.

From inspection of Figure E.3 it is evident that, at any fixed depth, it is feasible to breathe a range of gas mixtures without ill effects. For example, at a depth of 200 feet, the mixture could be as lean as 3 percent oxygen (0.21 atm) or as rich as 17 percent oxygen without encountering exposure time limitations. Likewise, a fixed oxygen

concentration in the breathing mixture will support dives to a range of depths. A mixture containing 10 percent oxygen, for example, would permit operations between 36 and 360 feet, with the possibility of short excursions as deep as 600 feet. It is important to again note that anoxia can occur if lean mixtures intended for deep operations are breathed during ascent and decompression. It is necessary to provide higher oxygen percentages at shallower depths to stay within the working range indicated in Figure E. 3.

E. 5. 2 Diluent Gases

The oxygen percentages shown in Figure E. 3 would be appropriate with any diluent gas or mixture of diluent gases that might be applicable to diving. Oxygen-nitrogen mixtures, including air, can be used freely if nitrogen partial pressure is limited to 3 atm, the pressure at which the first symptoms of nitrogen narcosis appear, and nitrogen partial pressures to 5.5 atm can be used with care by experienced DSS personnel for short periods. (2) (This is equivalent to diving at 200 feet with air.) For greater depths, helium is the diluent gas now generally used because it does not produce a narcotic effect at any practical diving depth and because its low density reduces breathing effort. The principal disadvantages of helium are its limited availability and resulting high cost, the effect that it has on the voice that makes it difficult to communicate, and the high leakage rates experienced in joints and seals. Nitrogen at partial pressures up to 3 atm can be mixed with helium as a means of conserving helium, improving speech intelligibility, and reducing cost, but precise information on physical and engineering properties of helium-nitrogen-oxygen mixtures is not available at the present time.

Hydrogen has been proposed as a diluent gas for depths beyond 1000 feet because of its low cost and because its density is half that of helium. However, the effects of hydrogen on body tissues at high pressures have not yet been explored. Furthermore, hydrogen-oxygen mixtures are readily ignited by static-electricity discharges unless oxygen concentrations are below the combustible limit, which is at 6 percent oxygen at 1 atm pressure. (4) Explosive limits of oxygen-hydrogen mixtures have not yet been investigated at high pressures.

E. 5. 3 Decompression Considerations

Decompression considerations also influence the selection of breathing-gas composition. The length of the decompression period is a function of the partial pressure of diluent gas (helium or nitrogen) in the breathing mixture. The decompression period can be shortened by using oxygen concentrations close to the toxic limit during a scheduled diving period and during the decompression period. (2, 3) This approach is most effective for dives at shallow to moderate depths where the proportion of oxygen can be large enough to significantly reduce the partial pressure of diluent gas. Under marginal conditions, use of a high-oxygen mixture may eliminate the decompression period entirely. Oxygen is not normally a limiting factor in decompression because it is metabolized rather than taken into simple solution.

E. 5. 4 CO Levels

Although experimental data relating CO concentrations to toxic effects in helium-oxygen mixtures are not now available, effects can be predicted with reasonable assurance based upon CO-O₂ ratios. Accordingly, it is recommended that, for the present, CO limits for routine working exposure be based upon a constant CO-O₂ ratio equivalent to 1 ppm CO for each percent of oxygen in the breathing gas. On this basis, the limit for air containing 21 percent oxygen would be 21 ppm CO, and the limit for a breathing gas containing 2 percent oxygen would be 2 ppm CO.

It should be mentioned that far higher concentrations than those mentioned above can be tolerated in emergencies with levels of discomfort. For example, in air at atmospheric pressure, exposure to a level of 150 to 250 ppm CO for many hours will cause a severe headache, and a level of 1600 ppm CO will cause confusion and collapse within 1 hour. Using the CO-O₂ criteria above, when working in a saturation-diving environment containing only 2 percent oxygen, a headache should occur with a CO level of 15 ppm, and confusion and collapse should be expected with a CO level of 160 ppm. The time before collapse should be reduced in inverse proportion with CO and O₂ partial pressures. (5)

Analyses of breathing gases in SEALAB indicated levels of about 0.3 ppm CO in oxygen manifolds and about 0.6 ppm CO in He manifolds and mixed-gas lines (1.) These levels would be well within the recommended limit of 3 ppm CO for an atmosphere containing 3 percent oxygen. However, additional CO can enter the system from diver metabolism, and activities such as smoking (not normally authorized in U.S. Navy DSS) or cooking. Thus, CO concentration in a habitat would normally be expected to increase with time. CO can be converted to CO₂ with catalytic burners and removed by the CO₂ absorber. It can also be diluted to acceptable concentrations by periodic ventilation of the living space. Current DDS life-support systems provide Baralyme and activated-carbon canisters to absorb CO₂ and odor, but these do not reduce CO levels. Future DSS may provide means for CO removal. Without a CO removal system it may be necessary to occasionally ventilate a DSS to dilute CO to acceptable concentration.

E.5.5 CO₂ Levels

Figure E.4 shows CO₂ tolerance zones as a function of percentage CO₂ and depth, at partial pressures taken from Figure E.2 for a 1-hour exposure period. As with oxygen, the physiological effects of carbon dioxide depend upon its partial pressure in the blood and therefore in the breathing gas. The percentage of carbon dioxide in the breathing gas that can be tolerated at diving depths decreases with depth, and the respiratory volume required to ventilate the lungs at depth remains approximately equal to that at sea level.

If a DSS breathing circuit includes volumes from which exhaled air is rebreathed, these volumes must be ventilated to dilute the carbon dioxide to a nontoxic level. If all of the carbon dioxide produced is mixed with all of the ventilating gas, the reduction of partial pressure depends only upon the ratio of carbon dioxide production rate to dilution-gas flow rate. This ratio must be about 1:100 to limit carbon dioxide to 0.01 atm partial pressure, or 1:50 for 0.02 atm pp CO₂.

The quantity of ventilation gas can be reduced if the concentration of carbon dioxide can be reduced by other means such as absorption by a carbon dioxide absorbent. Thus, DSS might employ canisters of absorbent through which breathing gas is circulated to reduce the carbon dioxide level, thus reducing the quantity of ventilation gas required.

Unventilated dead space has a significant effect on the respiratory volume required for control of carbon dioxide. Examples of unventilated dead space are the natural volume of the mouth and throat, the volume of a mouthpiece between non-return valves, and the volume of an open full face mask. The effect of dead space is to physiologically increase the volume of inhalation by the amount of the volume of the dead space. Thus, if normal tidal volume is 1 liter and the dead space in a full face mask of 1/2 liter is added, the inhalation volume needed to maintain a normal carbon dioxide level in the blood increases to 1.5 liters. The effort of breathing the extra volume reduces the maximum productive work level and increases the quantity of breathing gas needed by 50 percent. If an inhalation volume of 1.0 liter is maintained, only 0.5 liter of fresh gas would be obtained with each inhalation, and this would double the respiratory frequency and gas consumption. It is always desirable to minimize dead space in any diving equipment to the extent possible while meeting other requirements.

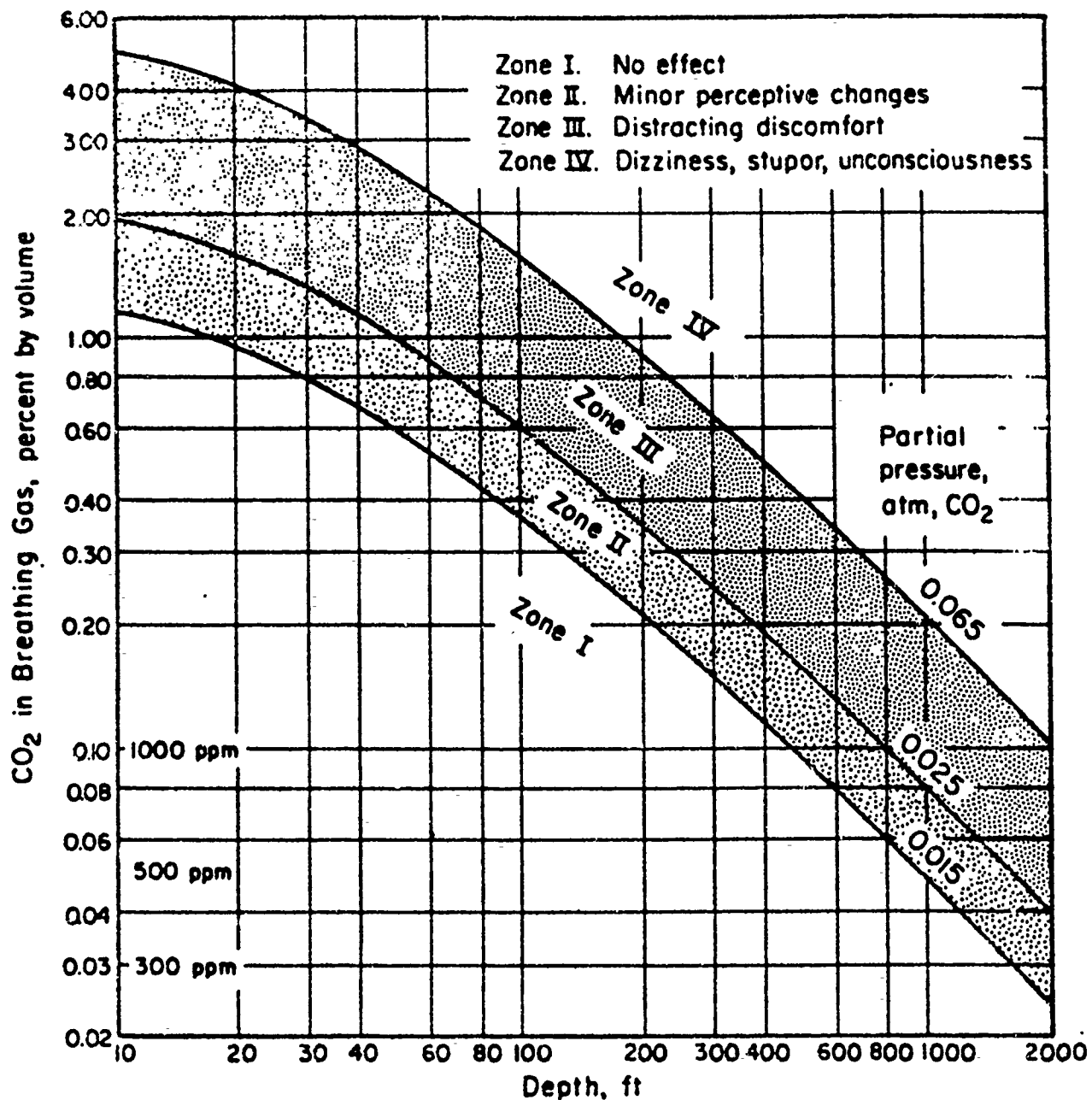


FIGURE E.4 RELATION OF CO₂ TOLERANCE ZONES TO DEPTH AND PERCENTAGE OF CO₂ IN BREATHING GAS

(Tolerance zones from Figure E. 2 for 60 minute exposure)

REFERENCES

- (1) F. W. Williams, U. S. Naval Research Laboratory, "Source of Contaminants in Diving Systems," Research Report No. 6-70, Proceedings: Purity Standards for Divers' Breathing Gas Symposium, July 8-9, 1970.
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- (3) C. J. Lambertsen, "Limitations and Breakthroughs in Manned Undersea Activity," Supplementary Transactions of 2nd Annual MTS Conference, June 27-29, 1966, Marine Technology Society, 1030 15th Street, N. W., Washington D. C. 20005.
- (4) B. Lewis and G. von Elbe, Combustion, Flames, and Explosion of Gases, Academic Press, Inc., 1951.
- (5) J. D. Bloom, M. C., USN, "Some Considerations in Establishing Divers Breathing Gas Purity Standards for Carbon Monoxide," Research Report No. 6-70, Proceedings: Purity Standards for Divers' Breathing Gas Symposium, July 8-9, 1970.

APPENDIX F

GENERAL GUIDELINES FOR ATMOSPHERIC EVALUATION OF MANNED DSS

F.1 INTRODUCTION

It is imperative that a DSS provide an acceptable atmosphere for its operators/occupants. To assure such an atmosphere, it is necessary to check the makeup of the atmosphere under operating conditions. This includes the search for contaminants which may enter the DSS by way of materials of construction, as cumulative contaminants from compressed gases and from other sources such as solvents used to clean the system. The amounts of contaminants found must be considered and evaluated in terms of personnel safety. This evaluation should take into account the particular contaminants and their toxic and corrosive hazard potentials as well as their source and potential methods of their removal. Whether or not the DSS is hyperbaric, the length and type of its planned missions must be considered.

There are three basic requirements for the evaluation of closed atmospheric systems: a valid sampling program, effective analysis techniques, and meaningful interpretation of the data obtained. The approaches to be used to satisfy these requirements will depend somewhat on the atmosphere under consideration; that is, whether the system is to be operated at normal or high pressure, what gas mixture will be used, the expected duration of the dive (or "closed" test) and the type of atmosphere control equipment employed. The atmosphere evaluation should encompass both the "livable" volume and the compressed gas supply.

A DSS which will operate normally at one atmosphere should be subjected to two evaluation trials. The first should be an unmanned trial to ascertain the habitability of the DSS primarily in terms of trace contaminant buildup. The second should be a manned mission intended to ascertain the effectiveness of the atmosphere control equipment. For DSS that operate at pressures higher than one atmosphere, an unmanned run at the maximum expected operating pressure, for the purpose of evaluating the life support system under actual operating conditions is also necessary. Proof of the performance of the carbon dioxide removal equipment at the lowest operating temperature and maximum operating pressure is of particular importance.

F.2 SAMPLING APPARATUS AND PROCEDURES

There are two sorts of sampling which are needed for complete evaluation. The first is on-site sampling and analyses for atmospheric contaminants which may not be stable; the second is sampling for laboratory evaluation. During sampling, if any unusual odors are detected, their origin should be ascertained and corrected if necessary. Olfactory detection of some compounds such as hydrogen sulfide and ammonia is much more sensitive than chemical means.

When possible, it is advantageous to obtain atmosphere samples at higher than ambient pressure to facilitate later analysis.

The recommended procedure for obtaining an atmosphere sample, using stainless steel bottles and a suitable compressor, is as follows:

- a. The stainless steel bottles should be evaluated for cleanliness before using them for sampling.*
- b. Open valve to previously evacuated steel bottle and allow to come to atmospheric pressure inside the submersible being evaluated.
- c. Thread flask into tee or nipple as provided at the pressure gauge connection on the pump.
- d. Pump flask to between 50 to 60 psig.
- e. Release pressure. Repeat pumping procedure three times. Do not release pressure final time.
- f. Close valve to flask.
- g. Turn off compressor.

Samples from high pressure gas systems can be obtained by making suitable connections. Provision should be made so that the connecting piping between the pressurized system and sampling bottle can be well purged to allow collection of a valid sample. All pressurized gas systems and gas supplies to be used with the sealed DSS should be sampled and analysed, including any such gas supplies which could accidentally be vented inboard.

Samples from pressurized capsules or storage flasks can be obtained directly without the use of the pump. Extreme caution should be exercised to assure that the bottle is not filled beyond its rated pressure.

In the event that there is no power available to run the compressor, the valves on evacuated sample bottles located inside the DSS can be simply opened and then reclosed to collect a sample at the internal pressure of the DSS. In such a situation, each bottle should be equipped with an absolute pressure gauge with which to note the bottle pressures before the valve is opened and after the bottle pressure has equalized. The gauges also serve to ascertain that sample bottles remain fully evacuated until just prior to use, thereby assuring a valid atmosphere sample from the DSS.

F.3 ANALYTICAL PROCEDURES

The second major phase in atmosphere evaluation is the selection of appropriate techniques for analysis. The techniques and instruments which can be used will vary with the type of closed system being evaluated, the operating conditions expected, and the particular gases and contaminants suspected or of interest. Some suggestions which may be applied to specific contaminants or groups of contaminants are presented. Further details appear in other sections of this appendix.

* It is important that the sample bottles do not retain a memory of previous usages. The cleanliness of each bottle can be determined as follows: Pressurize the sample bottle with dry oil-free nitrogen and allow it to come to thermal equilibrium (2-4 hours depending on temperature). The nitrogen contained in the sample bottle can then be analyzed by appropriate procedures given later in this appendix.

a. Total Hydrocarbon Analysis

Consider first the bottled samples from either manned or unmanned tests. The detection and determination of specific contaminants is a difficult and time-consuming task. It is suggested that a total hydrocarbon analysis of the sample be obtained using a gas chromatographic system equipped with a back-flush valve, such as is the NRL Total Hydrocarbon Analyzer. The THA is, basically, a gas chromatograph equipped with a flame ionization detector. In normal operation of a gas chromatograph, a sample is introduced into a partitioning column and is swept through the column by means of a carrier gas (helium, nitrogen or air) to the detector. The THA differs from the normal gas chromatograph in that it, additionally, has a "back-flush" capability. Back-flushing is reversal of the flow of the carrier gas at a selected time after the sample has been introduced into the column. Instead of allowing the components to separate in the partitioning column into individual components which are then passed into the detector, back-flushing the column regroups the sample into one peak, which then is eluted from the column into the detector. Most commercial gas chromatographs equipped with a flame detector can be modified to perform the same analysis.

In the event that the total hydrocarbon value, excluding methane, based on a n-hexane standard or equivalent, exceeds 15 mg/m^3 , the total hydrocarbon mixture should be analyzed further for specific contaminants, providing analytical information as to the presence of specific compounds (such as benzene) which might be present in unacceptable concentrations. The total hydrocarbon value of 15 mg/m^3 , per se, should not disallow the acceptance of the atmosphere under evaluation. Detailed analyses can be done by normal elution gas chromatography, mass spectrometry, infrared analysis or a combination of these techniques.

b. Chlorinated Hydrocarbons

One specific class of compounds that is included as part of the "total hydrocarbons" is the halogenated hydrocarbons (halocarbons). The halocarbons generally encountered, in almost all cases contain chlorine and can be called "chlorocarbons." These compounds are of special interest because of their high degree of toxicity as compared to hydrocarbons and the corrosiveness of their degradation products.

The total chlorocarbon content of the atmosphere should be determined and, if found to be in excess of 15 mg/m^3 , a sample should be further analyzed for specific contaminants. An instrument capable of measuring total chlorocarbons at this level is the Dohrmann Microcoulometer. Trichloroethylene is a compound that merits special consideration and should be looked for specifically in atmospheres from all closed environmental systems that use a caustic for CO_2 removal. The significance of this compound is discussed later in more detail.

Often, atmospheres are found to be contaminated with refrigerants or chlorinated cleaning solvents such as Freon-113. The NRL Total Hydrocarbon Analyzer is capable of detecting many of the very volatile refrigerants and solvents at the same time that a total hydrocarbon analysis is being carried out and is also capable of detecting some of the less volatile solvents by its use in a different mode. Obviously, if chlorinated contaminants are found to be present at levels in excess of 15 mg/m^3 , it is useless to run a total chlorocarbon analysis. The sample should then be analyzed directly for individual chlorocarbons. This can be done through use of a gas chromatograph equipped with an electron capture detector to a microcoulometric detector combined with a suitable concentrating technique.

c. Carbon Dioxide

The carbon dioxide CO₂ concentration in the atmosphere during a manned evaluation should be followed closely by an on board monitor during the dive and verified as soon as possible by gas samples obtained in steel bottles during the dive. The CO₂ level can be determined by several means such as gas chromatography, nondispersive infrared analysis or an equivalent method. If gas chromatography is used, the preferred detection method, except at very low concentrations, is thermal conductivity.

d. Reactive Contaminants

Some potential contaminants are too reactive or absorptive to allow quantitative sampling by the pressurized bottle technique. Such compounds must be analyzed in the DSS during closed tests. Reactive contaminants include ozone, sulfur dioxide, hydrogen sulfide, phosgene and nitrogen dioxide. Detector tubes should be suitable for the analysis of these compounds.

e. Carbon Monoxide

A trace contaminant of interest because of its toxicity and ubiquity is carbon monoxide. It should be monitored during any manned test by means of detector tubes. This contaminant can also be analyzed in the bottle samples. Gas chromatographic techniques are available which are based on either the electrical breakdown (Karmen) detector or conversion to methane and detection by flame ionization.

f. Mercury Vapor

Mercury vapor can be detected by means of detector tubes.

g. Aerosols

If, at the termination of the unmanned test or during the manned evaluation, any aerosol such as a mist, smoke or fog is seen, a sampling program should be undertaken to ascertain that it presents no hazard to inhabitants.

F.4 ATMOSPHERE EVALUATION PROCEDURES

The evaluation procedures to be used during the various trials must be based on the type of DSS and the type and duration of closed atmosphere operations planned. Analysis for atmospheric contaminants in the unmanned enclosures should be made before manned evaluations are conducted. Samples of the gas supplies to be used should be collected for analysis in order to establish the baseline level of contaminants.

a. DSS Designed to be Operated at One Atmosphere

(1) Unmanned Evaluation

Bottled gas samples for the unmanned evaluation should be taken at the beginning and at the termination of a "closed hatch" test. The duration of the test should depend on the length of time the DSS will be closed during an actual dive. With the short mission DSS, the test should be twice as long as the actual dive time. That is, for an average dive time of 8 hours the closed hatch test should last for 16 hours. In situations where

the expected mission time will be much longer, the closed hatch test should run at least 16 hours or longer. The test duration should be dictated by the type of DSS and its expected uses. As much of the equipment as possible within the DSS should be operating during the test. In DSS equipped with a charcoal (carbon) filter the charcoal should be removed prior to the unmanned test, thus simulating the most severe condition.

Analyses of the gas samples should be made by the methods described in paragraphs F.3a, -b, -c, and -e. Tests for mercury should be conducted in the DSS at the end of the closed test. Upon opening the DSS following the closed test, visual observation for aerosols should be made and note made of any odors which may be meaningful in the final evaluation of the system.

(2) Manned Evaluation

During a manned trial all systems should be in operation including the carbon filter system. This trial should last sufficiently long to evaluate the atmosphere control equipment. A bottled sample of the atmosphere should be taken at the beginning of the dive just after the hatch is closed and a final sample taken at the termination of the dive just prior to opening the hatch. These bottled samples should be analyzed for all contaminants listed in the unmanned evaluation previously described.

The carbon dioxide buildup during the manned trial should be monitored by means of instrumentation contained within the DSS and the data verified by laboratory analysis of the bottled samples. Detector tubes should be used during the dive to follow the carbon monoxide level. Detector tubes should also be used approximately halfway through and at the end of the dive to determine the presence of reactive gases like ozone, ammonia, sulfur dioxide, hydrogen sulfide, phosgene and nitrogen dioxide (so-called "nitrous gases"). If a suspicious odor or irritation of eye or mucous membranes is observed, tests for reactive gases should be made immediately. Tests for mercury should also be made during this trial. Note should be made of aerosols detected and appropriate action taken.

b. DSS Designed to be Operated at Hyperbaric Pressures

In hyperbaric systems, atmosphere sampling should be done both at a pressure near one atmosphere and at the actual pressure at which the system is to be used.

The procedures used should be patterned after those described under "DSS Designed to be Operated at One Atmosphere." The low pressure evaluations can be made at one atmosphere, if feasible, or at the lowest practicable sea pressure equivalent. Trace contaminants can be detected and identified more readily in the low pressure samples before the atmosphere has been diluted with high pressure gas. Identification of contaminants found in the low pressure sample could be useful both in determination of their sources and in assessing their seriousness. A sample of the gas used to pressurize the system should be obtained and analyzed to ensure that contaminants found actually arose from the chamber itself and were not introduced with the pressurization gas.

The high pressure gas systems associated with hyperbaric DSS should also be checked for contaminants as these systems could be a major source of contaminants in the chamber during actual use. This is especially true of O₂ systems in which the gas is consumed by the men and is added constantly to maintain the correct partial pressure. Contaminants in this gas would thus build up in the chamber over a period of time.

In view of the scarcity of information, at the present time, about the efficiency of CO₂ absorbents at high pressures and low temperatures, it is recommended that the CO₂ removal system in a hyperbaric DSS be evaluated in the unmanned chamber at working pressure and temperature. This would be especially important in chambers operated at low temperatures. Such an evaluation could be carried out by adding CO₂ to the system at a constant rate corresponding to its expected rate of production based upon the number of men in the chamber and by monitoring the CO₂ levels in the chamber by external measurements.

Atmospheric analyses should then be made on the manned chamber at one atmosphere pressure with all systems operational, as outlined in the preceding section.

F.5 ADDITIONAL DISCUSSION ABOUT CHLOROCARBONS

If human occupancy is planned, halogenated solvents, as a class, should be avoided in the selection of materials for the construction and maintenance of any closed atmospheric system. These remarks are particularly directed at chlorocarbons which have become widely used in the past few decades. Their hazard potential is of an insidious nature. This results from the fact that although the toxicity or corrosiveness of the parent compound may be relatively low, the products of their chemical reaction or thermal degradation are often toxic or corrosive.

Trichloroethylene is an example of a chemical compound whose reaction product is potentially hazardous. When passed through a bed of moderately heated alkali, a dehydrochlorination reaction occurs which yields dichloroacetylene.

Dichloroacetylene is an extremely toxic compound which must be excluded from closed atmospheres. Unfortunately, no analytical method is available for the direct analysis of dichloroacetylene in a complex atmospheric mixture at the required low levels of one ppm or less. Consequently, the precursor compound, trichloroethylene, must be kept at very low levels. Trichloroethylene can be detected at low concentrations in air. Because it is so insidious, trichloroethylene should not be used in closed atmospheric systems for any purpose.

The presence of carbon monoxide (CO) removal equipment in a DSS, more specifically a CO/H₂ burner, complicates the significance of the presence of halogenated hydrocarbons. Halocarbon compounds decompose in the CO/H₂ burner to form breakdown products which are detrimental to both man and materials. Thus the maximum allowable limit of a contaminant must be based not only upon its own toxicity, but also upon the toxicity of its breakdown products and the effects of the acidic products on equipment and machinery.

F.6 INTERPRETATION AND APPLICATION OF DATA

Sampling and analysis of atmospheric gases must be followed by a meaningful interpretation of data. After the identities and concentration levels of contaminants are established, evaluation of potential toxicity hazards must be made based on such guidelines as indicated in Appendix E, and publications of the Bureau of Medicine and Surgery and the Navy Toxicology Unit. Based on these considerations, concentration limits can be established for trace contaminants both as groups, such as total hydrocarbons, and specific compounds.

The effects of various contaminants should be interpreted in the light of the type of DSS involved, considering factors such as time and the effect of pressure. For example, the concentration value of 15 mg/m³ for either total hydrocarbon or total chlorocarbon is a signal for invoking detailed analyses for individual compounds. Finding totals for these

types of compounds in excess of 15 mg/m³, however, should not automatically cause rejection of the system being evaluated. Maximum limits, whether for individual compounds or for classes of compounds, could be different for each system being evaluated and thus should be established to be in accordance with the requirements for and demands of the particular system. Therefore, the types of atmospheric data taken, the conditions under which they are obtained and the interpretations which are made, should be fitted to the particular DSS under consideration. For example, the maximum acceptable limit for carbon monoxide in nuclear submarines, which operate at a pressure of one atmosphere, has been set at 25 ppm for continuous exposure of 90 days. Since the toxic effect of carbon monoxide is a function of its partial pressure, the concentration in ppm which is acceptable will decrease as the total pressure increases. Other factors to consider are length of exposure, presence of specific purification equipment, and type of mission expected.

Advice on toxicity considerations not covered in available publications may be obtained from the Navy Toxicology Unit, Naval Medical Center, Bethesda, Maryland.

APPENDIX G

GENERAL GUIDELINES FOR CLEANING BREATHING GAS SYSTEMS

G.1 INTRODUCTION

This Appendix provides general guidelines for developing cleaning procedures and criteria for breathing gas systems and have been specifically developed for breathing systems used in conjunction with all Navy man-rated Deep Submergence Systems. Examples of breathing gas systems in this category are metabolic oxygen, air, and HeO₂.

These general guidelines convey the latest experience gained by those knowledgeable in cleaning breathing gas systems. It is not intended to restrict the development or use of new ideas, procedures, hardware or equipment.

G.2 REFERENCES

G.2.1 Military Standards

MIL-STD-1246A - Production Cleanliness Levels and Contamination Control Program.

MIL-STD-767A - Cleaning Requirements for Special Purpose Equipment Including Piping Systems.

MIL-STD-1330 - Cleaning and Testing of Oxygen and Nitrogen Piping Systems.

G.2.2 Military Specifications

MIL-D-16791E - Detergents, General Purpose (Liquid NONIONIC).

G.2.3 NASA Specifications

MSC-SPEC-C-6B - Spacecraft Chemical and Cleanliness Requirements.

MSFC-SPEC-164A - Cleanliness of Components for use in oxygen, fuel and pneumatic systems.

KSC-123(D)O - Cleanliness Levels, Cleaning Protection and Inspection Procedures for parts, field parts, assemblies, subsystems and systems for pneumatic use in support equipment.

G.2.4 Other

BUSHIPS INSTRUCTION 9230.12A - Cleaning Procedures - Oxygen and Nitrogen Systems.

MARE ISLAND Process Instruction 0516-839.

SFBNSY Test No. 516T-2122 E - ASR diving system piping systems cleaning testing and certification.

NRL Memorandum Report 2122 Guidelines for Atmosphere Evaluation of Manned Small Submersibles and Chambers.

G.3 DEFINITIONS

G.3.1 Cleanliness Level

An established level of maximum allowable contamination based on size, distribution or quality in a given area or volume.

G.3.2 Contamination

Any foreign material.

G.3.3 Fiber

Particle having a length to width ratio of 10 to 1 or greater.

G.3.4 Micron

A unit of measure equal to one-millionth of a meter or thirty-nine millionths of an inch (0.000039 inch); e.g., 25 microns is approximately 0.001 inch.

G.3.5 Non-Volatile Residue (NVR)

Soluble material remaining after evaporation of a volatile liquid or determined by special purpose analytical instruments usually measured in milligrams per unit volume.

G.3.6 Particle Size

Particle size is expressed as the apparent maximum linear dimension or diameter of the particle.

G.3.7 Significant Surface

Any surface of an item or product which is wetted by the breathing gas and therefore is required to meet the established cleanliness level requirements.

G.4 GENERAL PROCEDURES

G.4.1 Remarks

There are two recognized procedures used to date for cleaning breathing gas systems.

a. The system is cleaned in individual elements prior to assembly and then assembled under controlled conditions.

b. The system is cleaned following assembly, usually by flushing.

Approach a.

If approach 'a' is used, careful records should be kept relating the total system to the individual components cleaned. This is to insure that each item in the system has been properly cleaned. The end result should be a simple system schematic drawing identifying each element of the finished assembled system and how cleanliness was achieved.

Approach b.

If approach 'b' is used, a record should be kept indicating where the cleaning agent was introduced and taken out, any jumpers used, the valve lineup during flush and the direction of flow. In addition, if flushing blocks are used, the removed valve internals should be cleaned in accordance with approach 'a'.

G.4.2 Sequence (Suggested)

Whether 4.1.1 or 4.1.2 or a variation of both is considered, the following general steps should be taken:

- a. Specified valves and components should be removed from the system and cleaned and tested separately where applicable.
- b.¹ Piping systems, minus specified valves and components, should be back flushed for particulate matter removal.
- c.¹ Piping systems should be hydrostatically tested to 1 1/2 times their working pressure.
- d. Piping systems should be cleaned for hydrocarbons.
- e. Piping systems should be flushed with dry oil free nitrogen until it is established that the gas is contamination free.
- f. Piping systems should be assembled complete with all valves and components and tested for tightness to their working pressure.
- g. An atmospheric analysis should be performed to insure all toxic materials have been removed.

G.5 CLEANING METHODS AND MATERIALS

G.5.1 General Remarks

The following comments are derived from experience gained in cleaning breathing gas systems. As noted in 1.3, it is not the intent of this section to restrict cleaning procedures, materials and agents to those mentioned below, but provide information based on experience. The agents below are those which have been primarily used in the past to clean breathing gas systems. For additional information on various cleaning agents MIL-STD-1246A is suggested.

¹ It is important to note that a system should be flushed for particulate matter before strength testing is accomplished. Experience has shown that particulate matter can be driven into cracks, crevices, and software if particulate matter is not removed.

G. 5. 2 Trisodium Phosphate

It is suggested that BUSHIPINST 9230.12A² be used as general guidelines for generating cleaning procedures in conjunction with this agent.

The cleaning agent, Trisodium Phosphate, is considered to be the most acceptable agent for total system flush (4.1 approach (b)), primarily due to the fact that it has no potential for producing toxic materials if inadvertently left in the system.

The procedure as outlined in BUSHIPINST 9230.12A is somewhat complex.

Care should be taken to insure that all of the cleaning agent has been removed from the system. If the cleaning agent is not completely removed, particulate matter may result possibly creating problems with precision components in the system.

Problems have also occurred with "Parkerized" components (bottles) after using water base detergents including Trisodium Phosphate. If the component is not completely dried immediately after flushing, rusting will occur thus creating particulate matter. It is recommended that a water based cleaning agent not be used in conjunction with these items (bottles).

G. 5. 3 Trichlorotrifluoroethane

It is suggested that MIL-STD-1330 be used as general guidelines for generating cleaning procedures in conjunction with this agent.

Difficulties have been encountered in removing this agent from piping systems, especially from dead end piping and flasks. This has been true for both the cleaning and purging operation since this agent is a liquid at normal temperatures with a boiling point of 117.6°F at one atmosphere.

The agent itself is not a very toxic material at atmospheric pressures, nor does it have a deleterious effect on metal systems. This agent, however, in the presence of a CO/H₂ burner does break down into hydrogen chloride (HCL) and hydrogen fluoride (HF) gas.

The production of these two components would give rise to both a toxic and corrosive problem in the concentration range of one ppm by volume.

Another difficulty encountered is incompatibility with synthetic materials such as Nylon, Tygon, rubber, plastic and other materials that may be used in typical breathing gas systems. In view of the above discussion, the following precautions should be taken:

- a. All non-metallic components should be checked for compatibility with this agent and removed where applicable.
- b. Care should be taken to insure that all the agent is removed after cleaning especially in systems which include a CO/H₂ burner.
- c. This agent should not be used in conjunction with systems with a large number of pockets (low points in the system) where cleaning agents might collect.

² Requests for copies of this document should be sent to:

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5801 Tabor Avenue
Philadelphia, Penn. 19120

d. Once cleaning has been accomplished, the system/component should be flushed (and baked where practical) several times to insure that all of the cleaning agent has been removed.

e. A gas sample should be taken from the completed system to assure that all of the cleaning agent has been removed. The system should be undisturbed for 24 hours before this sample is taken. Acceptable limits for trichlorotrifluoroethane should be 5 ppm by volume.

G.5.4 Trichloroethylene

This agent must not be used in conjunction with breathing gas systems because of the potential hazard it presents. When passed through a bed of moderately heated alkali (CO_2 removal chemicals) a dehydrochlorination reaction occurs which yields dichloroacetylene.

Dichloroacetylene is an extremely toxic compound which must be excluded from closed atmospheres. Unfortunately, no analytical method is available for the direct analysis of dichloroacetylene in a complex atmospheric mixture at the required low levels of 1 ppm or less. Consequently, the precursor compound trichloroethylene must be kept at very low levels.

If under dire circumstances it is considered absolutely necessary to use this agent, or if it has been found that a component has been inadvertently cleaned with this agent, the following steps should be taken:

a. After cleaning has been accomplished, the system/component should be purged (and baked where practical) several times.

b. A gas sample should be taken to insure that all of the cleaning agent has been removed. The system should be undisturbed for 24 hours before the sample is taken. Acceptable limits for trichloroethylene should be 1 ppm by volume.

G.5.5 Non-Ionic Detergent

It should be noted that this discussion is limited to MIL-D-16797 Type I (water soluble) agents. Non-ionic detergents are primarily used to decrease the surface tension of the mixture. This improves wetting of the surface (e.g., allows the cleaning agent to move easily and penetrate into small cracks).

When using this agent the following precautions should be taken:

a. The specific agent should be checked to insure that it produces no toxicological problems.

b. The specific agent and its concentration should be checked with respect to the cleaning temperature. Concentrations should range below 1%. Problems have occurred at high concentrations and temperatures. Some of these agents have precipitated out causing a gel to form on the internal portion of the system.

G.5.6 Ultrasonic Cleaning

The item to be cleaned should be immersed in a suitable bath of cleaning solution that is energized by an appropriate ultrasonic device. The cleaning solvent or solution

and the frequency of the ultrasonic energy should be carefully selected to be compatible and effective. This method should not be used on items which may be degraded by sonic energy unless precautions are taken that are demonstrated to provide effective protection. For typical breathing gas system components, it is recommended that 10 watts/m² be applied for 3-5 minutes.

G.6 SAMPLING AND ANALYZING

G.6.1 General Remarks

As noted in G.1 any proposed techniques for both sampling and analyzing will be acceptable provided it can be established by sound engineering principles that the resulting system is cleaned to the necessary tolerances. The following procedures which relate system size to cleanliness have been successfully applied by the aerospace industry.

G.6.2 Sampling Techniques

G.6.2.1 Small Components

A 500 ml (minimum) test solution is used to determine the particle population and the nonvolatile residue on significant surfaces of small components (less than 1.0 square foot in surface area).

- a. Divide the 500 ml test solution into quantities in proportion to the surface area of the individual components used to make up 1.0 square foot of surface area.
- b. Flush each component with proportionate share of test solution.
- c. Collect the flushing solvent for the analysis of the sample as applicable.
- d. Thoroughly dry components after completion of flushing operation.

G.6.2.2 Components 1.0 Square Foot in Surface Area

A 500 ml test solution used to determine the particle population and the nonvolatile residue on the surfaces of the components having significant surface areas from 1.0 square foot through 5.0 square feet should be prepared by flushing the test solvent over the significant surfaces and collecting the solvent for the analysis. The component should be thoroughly dried after completion of flushing operations.

G.6.2.3 Components with Surface Areas Greater than 5.0 Square Feet

A test solution to determine the particle population and nonvolatile residue on the significant surfaces of components having significant surface areas greater than 5.0 square feet should be prepared as follows:

- a. Flush the significant surfaces with 100 ml (maximum) of test solvent per square foot of surface area.
- b. Collect the flushing solvent.
- c. If more than 500 ml of test solvent is used, the flushings should be thoroughly agitated and a 500 ml sample be taken from the total quantity of flushing solution.
- d. The component should be thoroughly dried after flushing operation (step (a)).

G.6.3 Analytical Techniques

G.6.3.1 Particulate Sample Analysis:

a. Filtering Procedure:

- (1) Using forceps, remove Millipore disc from container, rinse grid-marked surface with filtered petroleum ether and place grid-marked side up on Pyrex Filter Holder Base.
- (2) Lock funnel to base with spring clamp.
- (3) Pour entire contents of sample bottle into funnel.
- (4) Rinse sample bottle with Millipore filtered solvent and add contents to funnel.
- (5) Apply vacuum to filter flask. When filtration is approximately one half complete, release vacuum.
- (6) While some liquid still remains in funnel, use Millipore filtered solvent to carefully rinse funnel walls.
- (7) Apply vacuum and pull remainder of fluid through Millipore filter disc. Do not subsequently rinse funnel walls or filter surface (to avoid disturbing the even distribution of particles on filter surface). Release vacuum.
- (8) Open filter holder. Using forceps, immediately place Millipore filter in clean Plastic Disposable Petri Dish identified with sample number.

b. Counting Procedure:

- (1) Install a measuring eyepiece disc in the eyepiece assembly of the microscope (either lens if a binocular microscope). Place a stage micrometer on the microscope stage.
- (2) Adjust the microscope illuminator intensity and position for maximum definition of the stage micrometer scale as viewed through the microscope.
- (3) Calibrate the measuring eyepiece for each magnification to be used. Post chart near microscope for all future work.
- (4) With forceps, gently float Millipore filter on film of immersion oil in cover of Plastic Petri Dish. Draw filter over rim of cover to remove excess oil from bottom of filter.
- (5) Place Millipore filter on 2 x 3 glass slide on microscope stage (lightly greasing the slide is desirable in reflected light work to hold filter flat and in place).
- (6) Move microscope stage so that particles on Millipore appear to pass under the measuring eyepiece. Count the number of particles in designated size ranges on the entire filter pad. Particles should always be sized by their longest dimensions. Fibers (particles with a ratio of length to width greater than 10:1) should be listed separately.

(7) It is always a good practice to prepare a blank analysis, proceeding through all filtering and counting operations without introducing any sample, to determine the "background" count. This is an excellent measure of cleanliness of glassware solvent and technique. Blank counts should not exceed 10% of control limits established for the fluids under test.

c. Record results.

G.6.3.2 Nonvolatile Residue

G.6.3.2.1 Analysis by Gravitational Means

The filtered sample (500 ml nominal volume) should be analyzed for nonvolatile residue content to determine acceptability as follows:

- a. Transfer 500 ml of the solvent into a clean degreased 800 ml beaker.
- b. Evaporate the solvent to 10 to 20 ml volume in a steam bath.
- c. Transfer the solvent to a constant-weight (within 0.3 mg) tared 30 ml weighing bottle, weighted to the nearest 0.1 mg.
- d. Continue evaporation to a volume of 5 plus or minus 0.5 ml. Do not let the solvent evaporate to dryness.
- e. Place the weighing bottle in a constant temperature oven at 221 to 230 degrees F for 1.5 hours.
- f. Cool weighing bottle in a desiccator and then weigh to the nearest 0.1 mg.
- g. Return the weighing bottle to the constant temperature oven for one-half hour.
- h. Repeat f. If the difference between the weights is greater than 0.3 mg, repeat step g. until the difference between successive weighing is 0.3 or less.
- i. Compare the results obtained from used solvent with the results obtained from unused solvent. The difference between the weights should not be greater than the increase specified for the affected item (based on surface area and total amount of solvent used for testing).

G.6.3.2.2 Analysis by Spectrophotometric Means

- a. Take a sample from the last few gallons of cleaning solution drained from the system. The sample size is dependent upon the sensitivity of the spectrophotometer used. It should be determined by establishing the weight of hydrocarbon oil which, when dissolved in 5 ml of Freon PCA, will reduce the transmission at 3.42 microns by 5 percent. By referring the amount of oil necessary to reduce 5 ml to an allowable limit of 5 ppm (by weight) of oil, calculate the additional amount of Freon PCA to be added to the initial 5 ml to establish the proper sample size. The calculated sample size should be about 400 ml when using a 0.5 mm absorption cell.

b. If the cleaning solution is trisodium phosphate, extract the sample with PCA. The extraction shall be performed in at least two steps, with PCA being allowed in the final step in an amount equivalent to at least one tenth of the cleaning solution sample size, arrived in a. above.

c. Filter the extract or the PCA solution sample through medium grade filter paper to remove suspended cleaning agent.

d. Over a steam bath evaporate the extract or the PCA solution sample to 5 ml.

e. Repeat steps b., c., and d. above with a blank sample of unused cleaning solution equivalent in size to the sample in step a.

f. Analyze the concentrated extracts from steps d. and e. in an infra-red spectrophotometer of the type previously specified. This is done by measuring the transmission of both extracts at a wave length of 3.42 microns. If the difference in transmission is 5 percent or less the system is to be considered clean. If this value is exceeded the systems shall be recleaned.

g. Evaporate the extract from step d., including the volume of extract used in the absorption cell during step f., to dryness and redissolve the residue in 5 ml of carbon disulfide (CS₂) (Caution -- Highly Inflammable) and analyze for phosphate ester lubricant. The base line transmission of the extract should be measured at a wave length of 10.35 microns. No blank sample is needed. If the reduction in transmission from the base # line is 5 percent or less, the system contains 0.4 ppm or less of phosphate ester lubricant and is considered clean.

G.7 CLEANLINESS

G.7.1 General Remarks

There are three major areas which should be looked at to insure that the system has been properly cleaned. They are as follows:

a. The system should be free from oil, grease and other nonvolatile residue which might present a fire hazard.

b. The system should be free from particulate matter which might damage system components.

c. The system should produce a breathing atmosphere which meets acceptable purity requirements for breathing gases (i.e., free from any toxic materials).

G.7.2 Required Cleanliness Levels

G.7.2.1 Nonvolatile Residue

The acceptable nonvolatile residue for all breathing gas systems should be no greater than .001 gm per square foot or equivalent.

G.7.2.2 Particulate Matter

Acceptability of particulate matter is primarily determined by high tolerance system components and the use of filters in the system. Therefore, the acceptance criteria substantiated by sound engineering principles should be chosen so that it will be adequate for the intended system.

The following tables developed by NASA are presented for information only. They are not intended to be used as a rigid criteria, but only as guidelines for forming the criteria of a particular system.

Suggested application

Level I	- For critical systems (for example, gas hearing and slosh measuring systems).
Level II	- For critical pneumatic parts, field parts and assemblies of applied systems.
Level III	- For liquid oxygen and fuel systems, parts, field parts, assemblies and systems.
Level IV	- For pneumatic parts, field parts, and assemblies of flow through applied systems.
Level V	- For parts, field parts, and assemblies of dead end services (for example, gauges, pressure switches, and relief valves).
Level VI	- For facility type systems and vent systems downstream of relief valves and check valves toward atmosphere.

G.7.3 Atmospheric Analysis

An atmospheric analysis should be performed to assure that all of the cleaning agent has been removed especially if cleaning agents G.5.3 or G.5.4 are used. This may be combined with the total system closed system atmospheric evaluation where applicable. Appendix F provides additional guidelines for Atmospheric Evaluation of Manned DSS.

G.7.3.1 Procedure for Obtaining Atmospheric Sample

The procedure that is used for obtaining an atmospheric sample, using stainless steel bottles and a compressor, is as follows:

- a. The stainless steel bottles should be evaluated for cleanliness before using them for sampling. *

* It is important that the sample bottles do not retain a memory of previous usages. The cleanliness of each bottle can be determined as follows: Pressurize the sample bottle with dry oil-free nitrogen and allow it to come to equilibrium (2-4 hours depending on temperature). The nitrogen contained in the sample bottle then can be evaluated by the appropriate analytical procedures.

TABLE G-1. CLEANLINESS REQUIREMENTS

Maximum particle population	LEVEL					
	I	II	III	IV	V	VI
No limit	Particle Size					
	0-20	0-20	0-35	0-50	0-100	0-175
40	21-40	21-45	36-60	51-140	101-280	176-540
10		46-70	61-95	141-230	281-460	541-950
3	41-80	71-95	96-135	231-320	461-640	951-1270
2		96-125	136-270	321-410	641-820	1271-1635
1	81-100	126-150	171-350	411-500	821-1000	1635-2000
0	101 +	151 +	351 +	501 +	1001 +	2001 +

TABLE G-2. FIBER LENGTH LIMITS BY CLEANLINESS LEVEL

Maximum population	LEVEL					
	I	II	III	IV	V	VI
No limit	Fiber Length Limits by Cleanliness Level					
	0-20	0-20	0-35	0-50	0-100	0-175
10	21-40	21-150	36-350	51-500	101-1000	176-2000
1	41-100	151-300	351-700	501-1000	1001-2000	2001-4000
0	101 +	301 +	701 +	1001 +	2001 +	4001 +

- b. Open valve to previously evacuated steel bottle and allow the pressure to equalize.
- c. Thread flask into tee or nipple as provided at the gauge connection on the pump.
- d. Pump flask to between 50 to 60 psig, where applicable. The compressor requires only a few minutes to bring the flask to this pressure, which is the maximum output pressure of the pump.
- e. Release pressure. Repeat pumping procedure three times. Do not release pressure final time.
- f. Close valve to flask
- g. Turn off compressor.

Samples from high pressure gas systems can be obtained by making suitable connections. Provision should be made so that the connection piping between the pressurized system and sampling bottle can be well purged to allow collection of a valid sample.

Samples from pressurized capsules or storage flasks can be obtained directly without the use of a pump.

Stainless steel bottles are generally rated for use only to 500 psig and extreme caution must be used. If the source of gas is higher than 500 psig, assure that the bottle is not filled beyond this rated pressure. In practice, a sample pressure of not more than 300 psig is adequate.

G.7.3.2 Analytical Procedures

It is recommended that a total hydrocarbon analysis be performed keeping a close lookout for the cleaning agent used. The total hydrocarbon analysis should be obtained on the sample using a gas chromatographic system equipped with a back-flush valve. An instrument capable of such a determination is the NRL Total Hydrocarbon Analyzer equipped with a flame detector and a silicone DC 200 column (see Appendix F). Most commercial gas chromatographs equipped with a flame detector could be modified to perform the analysis. In the event that the total hydrocarbon value (excluding methane, based on a n-hexane standard or equivalent) exceeds 15 mg/m^3 , the total hydrocarbon mixture should be analyzed further for specific contaminants. This is to provide analytical information as to the presence of specific compounds, such as benzene, which might be present in unacceptable concentrations. The total hydrocarbon value of 15 mg/m^3 , per se, should not disallow the acceptance of the closed atmosphere. Detailed analyses can be done by normal elution gas chromatography, mass spectrometry, infrared analysis or a combination of these techniques. The detection and determination of specific contaminants in this manner is a difficult and time-consuming task.

G.8 MAINTAINING THE SYSTEM IN A CLEAN CONDITION

G.8.1 Providing a Clean Gas

Care should be taken to provide a gas which is cleaned to the necessary tolerances of the system. Because of toxicological problems which occur in conjunction with chlorinated hydrocarbons (see G.5.2 and G.5.4), the supplier should certify in writing that either of

the following precautions have been taken:

a. The gas delivered has been analyzed, and contains no more than 0.1 ppm of halogenated compounds (trichloroethylene, carbon tetrachloride, etc.). Freon levels up to 1.0 ppm may be allowed.

b. That nowhere in the extraction, purification, storage, or handling of the helium has it been exposed to the contaminants noted above or to containers or hardware cleaned by them.

G.8.2 Charging Filters

In order to prevent any contamination from entering the system during charging procedures, a filter should be installed downstream from the charging connection as close to the charging connection as possible.

APPENDIX H

GENERAL GUIDELINES FOR DSS HANDLING SYSTEMS

H.1 INTRODUCTION

This appendix contains guidelines for the design of deep submergence system handling systems. Recommended design criteria are outlined and methods of verification are discussed.

H.2 DEFINITIONS

Added Mass Effect - Added force encountered when water is accelerated by a moving body.

Critical Item - A critical item is any item within a system, equipment or component, where failure would endanger life.

Design Load - the combined force due to the rated load, dynamic load, added mass effects, entrained water and drag.

Dynamic Load - the load imposed on a system due to weight and acceleration forces.

Fail-Safe - A fail-safe condition exists when the equipment has been designed so that when the operating power source (electrical, pneumatic, hydraulic or any combination of these) fails, the equipment is, by design, in a condition that is safe for personnel.

Handling System - that system or subsystem of the deep submergence system which is used in stowing, deploying, operating and retrieving the deep submergence system and is directly related to safety of DSS personnel.

Rated Capacity - the gross weight which devices can safely handle (i. e. lift, move, restrain) and still meet the requirements of the specifications (synonymous with capacity and safe working load).

Rated Load - the weight in air of the payload being handled plus the weight of all items normally carried by the payload.

Safety Factor - A constant equal to the ratio of either the yield or the ultimate strength of a material to the stress at the design load.

Static Load - Weight in air of the payload.

H.3 DESIGN CRITERIA

H.3.1 Operational Considerations

a. Environment - Environmental factors which should be considered in handling system design include sea state, air temperature, water temperature, precipitation, visibility at depth, wind velocity, and current. For the operational sea state specified, the uppermost value for wave heights of the significant wave or the 1/10th highest wave should be taken as the design wave. The period of maximum energy of the sea spectrum should be chosen as the design period.

b. Handling systems should operate so that deployment and retrieval of equipment at sea can be accomplished without the aid of divers, whenever possible.

c. Operation in a Damaged Condition - The handling system should remain operable after sustaining storm damage. Equipment and machinery should be capable of operating satisfactorily, maintaining adequate lubrication, and avoiding loss of oil or other vital fluids under the following conditions (these conditions should be specified by the designer):

- (1) Ship permanently trimmed down by the bow or stern.
- (2) Ship permanently listed to either side of vertical.

In addition, all handling system equipment should be operable under normal ship roll, pitch and heave conditions. These conditions should also be specified by the designer. Equipment should also be designed so that they can be operated manually in the event of a power or control failure and should be designed to be fail-safe.

d. Emergency Retrieval - Handling systems for DSS should have emergency retrieval operations capability.

II.3.2 Equipment Considerations

a. Loading

(1) Design Load - In cases where all of the design load effects are not experienced simultaneously, handling system components should be sized according to the highest design load condition that will be encountered.

(2) Unsymmetrical loading - When sizing members for handling systems which employ more than one load carrying member to support their payload, consideration should be given to factors which might cause unsymmetrical loading in the members. Such factors might be external water, free surface effects in internal tanks, or shift in ballast. To account for such unknown loading, a safe practice would be to increase the static load carried by each member by 10% of its value.

b. Factors of Safety

Suggested factors of safety for handling systems are given in Table H-1 and set forth values for factors of safety relative to the material used and the operating environmental conditions. These values are nominal values based on engineering experience and practices. Even though the design meets these suggested factors of safety, it does not relieve the applicant of the responsibility to provide material justification for each handling system component within the scope of certification.

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TABLE H-1. MINIMUM VALUES OF FACTOR OF SAFETY

Material/ Application	Manned		Unmanned (For Comparison) (Only)
	Non-Critical Component	Critical Component	
Cast iron	*	*	6
Fracture-resistance steel	3	3.5	2.5
Fracture-sensitive steel	3.5	*	3
Aluminum	3	5	2.5
Wire rope standing rigging	4**	5**	3**
Wire rope running rigging	5**	6**	5**
Fittings	3	4	3
Natural and synthetic rope	6**	7**	4**

* Not to be used in manned handling systems.

** Based on the ultimate or minimum breaking strength.

c. Materials

(1) Defects - Materials should be free from any defects and imperfections which might affect serviceability of the handling system.

(2) Material Compatibility - Bimetallic construction in handling system equipment that will be immersed in sea water should be avoided whenever possible. Whenever necessary, materials should be selected with consideration to their position on the electro-motive scale.

(3) Corrosion - Design of handling system equipment should be such as to eliminate hazards of parts becoming inoperative due to corrosive and wetting effects of salt spray and the extreme environmental conditions encountered in an exposed location on the weather deck of a ship. To prevent wire rope from corroding prematurely, synthetic coatings should be avoided. If a chafing material is needed, removable coatings should be used so visual inspection of the wire rope can be accomplished.

d. Automatic Release and Hook-Up System - The payload release and hook-up system should be automatic.

e. Load Control - Means should be provided by which the motion of the payload, particularly pendulum action, can be controlled by the handling system when the payload is suspended from the ship in a seaway.

f. Shock Mitigating Device - A means of controlled tensioning should be provided to reduce or prevent shock loading on the payload and the handling system due to surge in a seaway.

g. Naval Architecture

(1) Handling systems should be designed to be as light weight and compact as practical. Consideration should be given to the effect of the handling system on ship weight and stability.

(2) Handling system equipment should be located such as to be minimally affected by the ship's roll, pitch, and heave.

H.4 VERIFICATION OF ADEQUACY

H.4.1 Required Documentation

a. All components of the handling system within the certification scope should be identified as being either critical or non-critical.

b. The material adequacy of all handling system components within the certification scope which are in the critical category should be documented.

c. Design Calculations - Design calculations should include the following documents:

(1) An overall systems free-body schematic.

(2) A table indicating the various loading conditions used in the analysis.

(3) A load path analysis diagram showing how components of the system are loaded.

(4) When analyzing a critical component (see Table H-1), a free-body diagram of the item should be clearly shown within the calculation.

(5) Equations, assumptions and factors of safety used in the calculation should be clearly indicated.

H.4.2 Testing

Handling systems should be tested according to the following procedures:

a. Static test - The handling system equipment should be static tested to twice the design load of the specific piece of equipment. This load should be held for ten minutes. The static load should then be lowered with intermittent stopping to demonstrate the holding capacity of the brake. No visible permanent deformation should result from this test.

b. Overload - The handling system should be run through one complete cycle of its operation with 150 percent of the design load. A complete cycle would include unloading from the stowed position into the water, releasing, retrieving and restowing.

c. Rated Load - The handling system should be run through at least one complete cycle of its operation with its rated load. This test must be run at the specified operational speed of the equipment.

d. Non-Destructive Testing - Non-destructive test techniques should be employed to insure the soundness and quality of the handling system fabrication.

APPENDIX J
BIBLIOGRAPHY

The publications listed below are representative of those which may be useful to the applicant in preparing his DSS design for material certification. The most recent issue or revision of each should be used.

ASA B 31.1, Code to Pressure Piping

ASME Boiler and Pressure Vessel Code, Section II, Material Specifications

ASME Boiler and Pressure Code, Section III, Nuclear Vessels

ASME Boiler and Pressure Vessel Code, Section VII and Division 1, Unfired Pressure Vessels, and Division 2, Alternative Rules for Pressure Vessels

ASME Boiler and Pressure Vessel Code, Section IX, Welding Qualifications

BUMED Instruction 6260.6B, Hearing Conservation Program

BUMED Instruction 6270.3D BUMED letter SER 606 of 7 June 1969

Compressed Gas Association Pamphlet G-4.2, Standard for Bulk Oxygen Systems at Consumer Sites

Compressed Gas Association Pamphlet V-5, Diameter-Index Safety System

IEEE Publication 45, Recommended Practice for Electric Installations on Shipboard

MIL-B-16541, Bronze, Valve, Castings

MIL-B-23921, Bronze, Nickel Aluminum, Castings for Seawater Service

MIL-B-24059, Bronze, Nickel Aluminum, Rod Flat Products with Finished Edges, Shapes and Forgings

MIL-B-36212, Baralyme

MIL-C-15726, Copper-Nickel Rod, Flat Products, Flat Wire, Strip, Sheet Bar, Plate and Forgings

MIL-C-20159, Copper-Nickel Alloy 70-30 and 90-10, Castings

MIL-D-16791, Detergents, General Purpose (Nonionic)

MIL-E-917, Electric Power Equipment, Basic Requirements for Naval Shipboard use

MIL-E-16400, Electronic Equipment, Naval Ship and Shore, General Specification

MIL-F-22606, Flask, Compressed Gas and End Plugs for Air, Oxygen and Nitrogen

MIL-I-6866, Inspection, Penetrant Method of
 MIL-I-6868, Inspection, Process, Magnetic Particle
 MIL-L-20213, Lithium Hydroxide, LiOH, Technical
 MIL-M-16576, Metal, Gun, Castings
 MIL-O-9858A, Quality Program Requirements
 MIL-S-3289A, Steel, Plate and Disk, Carbon, Forging Quality
 MIL-S-16216, Steel Plate, Alloy, Structural, High Yield Strength, HY-80 and HY-100
 MIL-S-23008, Steel Castings, Alloy, High Yield Strength, HY-80 and HY-100
 MIL-S-23009A, Steel Forgings, Alloy, High Yield Strength, HY-80 and HY-100
 MIL-S-24094 use MIL-S-16113, Steel Plate, High Tensile, Hull and Structural
 MIL-T-1368, Tube and Pipe, Nickel-Copper Alloy, Seamless and Welded
 MIL-T-16420, Tube, 70-30 and 90-10, Copper-Nickel Alloy, Seamless and Welded
 MIL-V-24287, Sea Water Valves
 MIL-STD-101, Color Code for Pipelines and for Compressed-Gas Cylinders
 MIL-STD-210, Climatic Extremes for Military Equipment
 MIL-STD-271, Non Restrictive Testing Requirements for Metals
 MIL-STD-453, Inspection, Radiographic
 MIL-STD-767, Cleaning Requirements for Special Purpose Equipment including Fire Systems
 MIL-STD-882, System Safety Program for Systems and Associated Subsystems and Equipment, Requirements for
 MIL-STD-1246, Production Cleanliness Levels and Contamination Control Program
 MIL-STD-1247, Markings, Functions and Hazards Designations of Hose, Pipe and Tube Lines for Aircraft, Missile, and Space Systems
 MIL-STD-1330, Cleaning and Testing of Oxygen and Nitrogen Gas Piping Systems
 MIL-STD-1359, Cleaning, Methods and Procedures for Breathing Oxygen Equipment
 MIL-STD-00248 (SHIPS), Welding and Brazing Procedure and Performance Qualification
 MS-18116, Bolt, Bolt-Stud, Stud, Stud-Bolt, Nickel-Copper-Aluminum Alloy, Special Requirements
 MS-33586, Metals Definition of Dissimilar

BUSHIPS Instruction 9230.12A, Cleaning Procedures, Oxygen and Nitrogen Systems

BUSHIPS Instruction 9490.6, Shipboard High Pressure Compressor Air Systems-Inspect to Determine Need to Clean

BUSHIPS Instruction 9490.4B, Shipboard High Pressure Compressed Air Systems, Periodic Cleaning and Procedures for Cleaning to Prevent Fires and Explosions

BUSHIPS Instruction 9490.9, Procedure for Cleaning, Inspection and Coating High Pressure Air Flasks and Moisture Separators

NASA Management Instruction KMI 8610.6 (March 24, 1968), Attachment A; Minimum Criteria for Operations Involving Personnel in a Vacuum, Oxygen-Rich, or Potentially Oxygen-Rich Environment

NASA Spec 10509318 (MSFC), Hose Assemblies, Flexible, High Pressure, Specification for

NASA Spec MSC-SPEC-C-6B, Spacecraft chemical and cleanliness Requirements

NASA Spec MSFC-SPEC-164, Cleanliness of Components for use in Oxygen, fuel and Pneumatic Systems

National Bureau of Standards Handbook H28

NASA Spec KSC-123 (D), Cleanliness Levels Cleaning Protection and Inspection Procedures for Parts, Field Parts, assemblies, subassemblies and systems for pneumatic use in support equipment

NAVEXOS P422, Safety Equipment Manual

NAVSHIPS 0900-01-7000, Fabrication and Inspection of Brazed Piping Systems

NAVSHIPS 0900-006-9010, Fabrication, Welding and Inspection of HY-80 Submarine Hulls, Section 4

NAVSHIPS 0900-028-2020, Pre-Survey Outline Booklet for Manned, Non-Combatant Submersibles

NAVSHIPS 0994-001-9010, U.S. Navy Diving Manual

NAVSHIPS 0994-003-7010, U.S. Navy Diving Gas Manual

NRL Report 6957, Evolution of Engineering Principles for Fracture-Safe Design of Steel Structures, W. S. Pellini, September 23, 1969 (Naval Research Laboratory, Washington, D.C. 20390)

Ocean Systems, Incorporated, Report (May 1, 1969): Region of Non Combustible, Flammability Limits of Hydrogen-Oxygen Mixtures, Full-Scale Combustion and Extinguishing Tests and Screening of Flame-Resistant Materials

QQ-N-281, Nickel-Copper Alloy, Monel and R Monel, Bars, Plates, Rods, Sheets, Strips, Wire, Forgings and Structural and Special Shaped Sections

QQ-N-286, Nickel-Copper-Aluminum Alloy, Wrought

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QQ-N-258, Nickel-Copper Alloy and Nickel-Copper-Silicon Alloy, Casting

QQ-S-691C, Steel Plate, Carbon-Silicon, Carbon-Molybdenum, and Manganese-Molybdenum Alloys, Hot-Rolled (Marine Boiler Quality)

USAS B31.7, USA Standard Code for Pressure Piping, Nuclear Power Piping

USAS B57.1 - 1955, Compressed Gas, Cylinder Valve Outlet and Inlet Connections